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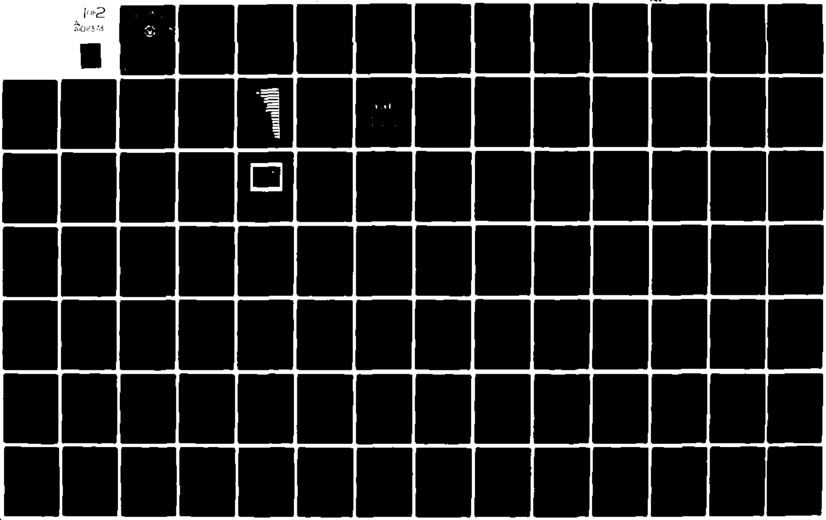

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THESIS

A PROPOSED FLIGHT SAFETY PROGRAM
FOR THE KOREAN AIR FORCE

by

Chong Kwan Lee

March 1981

Thesis Advisor: D.E. Neil

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2) System safety analysis
3) Critical incident technique.

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The safety program described in ~~the current~~ this thesis possesses the potential for reducing overall operational costs and maximizing aircraft availability. The end result of such a program can only serve to increase operational readiness and thereby maximize overall efficiency and military capability of the K.A.F.

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A Proposed Flight Safety Program for the Korean Air Force

by

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Major, Republic of Korea Air Force
Graduate of Korean Air Force Academy, 1971

Submitted in partial fulfillment of the
requirements for the degree of

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I. INTRODUCTION

Safety is generally recognized as an essential part in overall system operation. According to Lawrence (1976) safety can be defined as a judgment of the acceptability of risk. "Safety is the minimization of injury and loss resulting from nondeliberate acts such as accidents and natural calamities" (National Safety Council, 1973).

A function is safe if its risks are judged to be acceptable. This definition emphasizes the relativity and judgmental nature of the concept of safety. It also implies that two very different activities are required for determining how safe things are:

a. Measuring risk, an objective but probabilistic pursuit.

b. Judging the acceptability of that risk (juding safety), a matter of personal, social and economic value judgment.

System safety is required to prevent injury and damage in system design. Hammer (1972) in his Handbook of System and Product Safety suggests that injury or damage can result from four fundamental causes or combinations thereof:

a. material failure.

b. human error.

c. adverse characteristics of a product.

d. unusual environmental conditions.

Recently, personnel concerned with accident prevention have become more convinced that injury or damage from any of those causes can be prevented or lessened through good design and planning (Figures 1 and 2). Figure 1 suggests a model of the material failure/malfunction accident. The approach to the investigation, analysis, and prevention of mishaps caused by material failure/malfunction is FIRE (material failure/malfunction, system inadequacy, and remedial measure). They are defined as follows:

a. A material failure/malfunction (F) is a component or system that 1) ceases to operate entirely, 2) operates, but not as designed or intended, 3) operates as designed, however, operational needs require enhanced performance. A material failure/malfunction is considered for analysis only when it is judged to have caused or contributed to the mishap, not resulted from the mishap.

b. A system inadequacy (I) is an element of the aviation system that did not operate as intended or designed. An I is assigned only when it is judged to have caused, allowed, or contributed to the occurrence of an F. More than one I may be assigned to a given F.

c. A remedial measure (RE) is an action required to correct or at least reduce the operational impact of an I. The RE may be directed at any command level for implantation and is not to be restricted by current technology or budgetary, personnel, and equipment resources. More than one RE may be recommended for a given I.

Figure 2 presents a functional model of U.S. Army's Aircraft Accident to the pilot error accident among human errors. Items 1 through 8 are the basic elements of the aviation system. When one or more of these elements is out of tolerance, an overload (Item 9) is placed on the pilot's system role (Item 10) in that he must continue to perform his normal tasks while correcting or adjusting for the abnormal system condition. When this exceeds the pilot's ability to cope with it

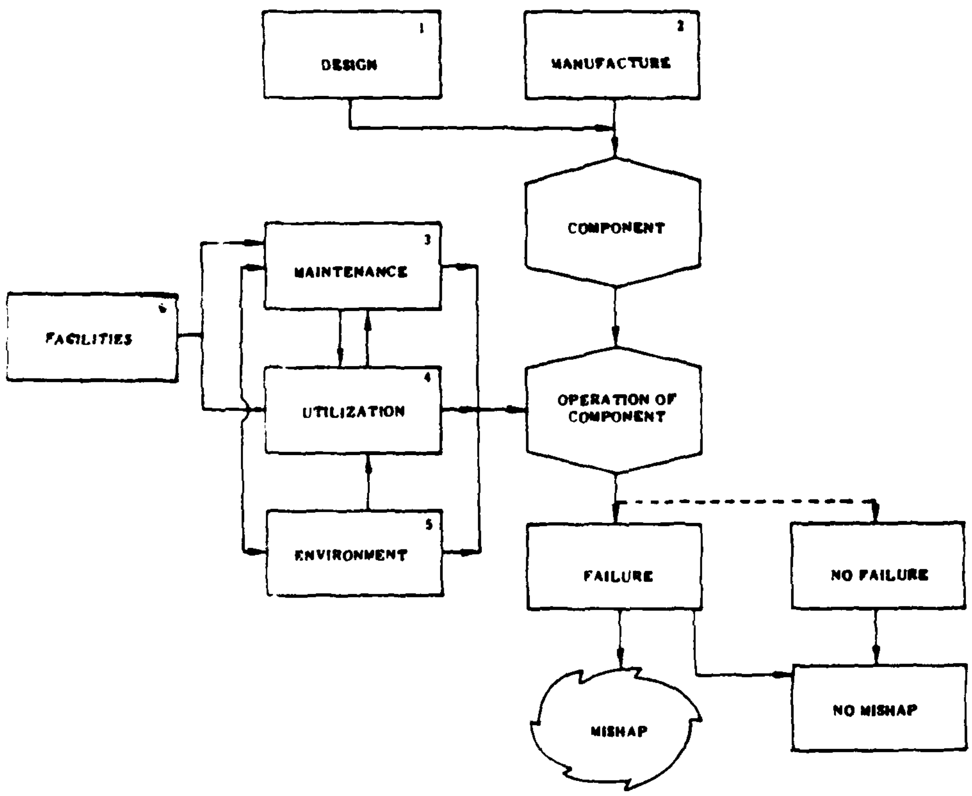


Figure 1. Model of Mishap Caused by Material Failure/ Malfunction (G. Dwight Lindsey and William R. Brown [1979], Appendix F-3)

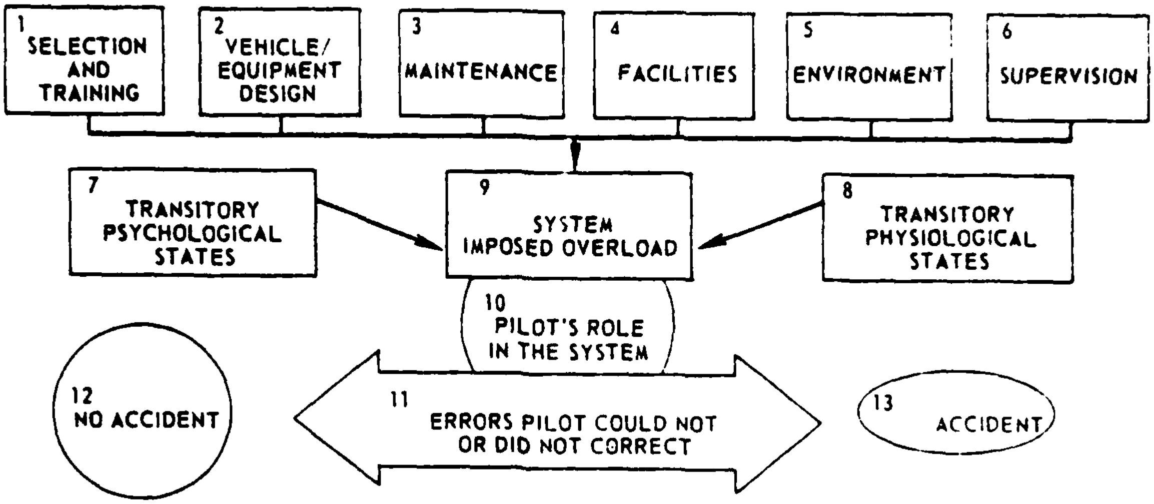


Figure 2. Model of Accident Involving Pilot Error (Ricketson, 1974)

or occurs at a critical time, he makes errors (Item 11) in his normal tasks and/or in handling the abnormal condition. Most of these errors slip by without causing an accident (Item 12). But, when events or circumstances operate unfavorably, the error leads to an accident (Item 13).

This approach views pilot error accidents as the result of the pilot's system role being overloaded by inadequacies of the pilot, other systems elements, or both. Accidents describe a point in time to look for system inadequacies. This model exemplifies an attempt to approach accident causes from a "systems" standpoint. Research has indicated that human error, unlike hardware difficiency, is rarely the sole factor in an accident. The applicability of this functional model is not limited to pilot error accidents. It is a model that may be used in any evaluation of a man-machine system.

The most commonly designated cause of accidents is human error. In the past decade, more than 70% of Korean Air Force aircraft accidents have been attributed to human error (Aircraft Accident Data of Korean Air Force, 1980). In accidents where material failure is recognized, it is often quite possible to continue tearing down the equipment until the precise portion that failed is isolated and the cause of the failure, whether it be corrosion, stress, faulty load conceptualization, or other factors, can be determined and redesign proposed. In case of human error, however, the static statement that a human being failed provides no guidance to future improvement. The need to reduce human error to its basic constituents as a means of obtaining insight into the causes of these failures has resulted in various approaches to segmenting human behavior for analytical purposes.

According to Florio and Stafford (1969), when the primary factor of an accident is attributed to human error the accident cause may be classified into five general areas:

a. Inadequate knowledge.

b. Insufficient skills.

c. Environmental hazards.

d. Improper habits and attitudes.

e. Unsafe behavior.

Each of these areas are discussed below:

Inadequate knowledge. Knowledge is the foundation for understanding and the spring-board for the development of desirable attitudes toward safe behavior. Ideally every individual should learn and appreciate safety rules. Adequate knowledge is vital if a person is to avoid hazardous situations and react properly in such a situation. Also, proper knowledge enables the individual to recognize and evaluate dangerous situations (i.e., be aware of tolernace limits of the system).

Insufficient skill. Attempting to perform tasks beyond one's ability level creates high-risk situations; thus skill level is an important determinant in accident prevention. Skills are affected by many things, such as strength, fatigue, attitudes, emotion, alcohol, vision, and others.

Environmental hazards. It is unrealistic to think that we can create a perfectly safe environment. Despite our inability to control our environment completely, only a small percentage of accidents are strictly attributed to environmental factors. Good engineering practices with good design reduce the environmental problems.

Improper habits and attitudes. Every worker should thoroughly understand the development of attitudes and their possible modifications.

Unsafe behavior. Unsafe behavior is the end result of man's failure to develop proper habits, attitudes, and knowledge concerning safety. Safe behavior entails responding correctly under all circumstances, and avoiding, when possible, high-risk situations. There is no excuse for purposely engaing in unsafe behavior.

Accidents are the result of many proximate and casual factors. These factors, or variables, interact to creat unsafe acts and unsafe conditions, or both, which can terminate in an accident causing injury, death, or property damage. An unsafe act or condition alone, or in some combination, if occurring at the right time may create an accident.

It is axiomatic that effective prevention must have a focal point of application. This implies that the probable cause of future accidents can be predicted. This, in turn, implies that the causes of past accidents have been determined.

The cost of accidents is high. In the past decade from 1970, the cost of aircraft accidents in the Korean Air Force approaches $50 million (not including piloes)[Aircraft Accident Data of Korean Air Force, 1980]. As a country that has small numbers of aircraft, this represents a tremendous cost. In the case of the U.S. Navy/Marines, the total accident cost (Figure 3) is greater than the K.A.F. For ultimate efficiency with maximum operational readiness and minimum cost, more detailed accident prevention programs must be followed. Accident prevention is best pursued within the framework of a systematic program (Figures 4, 5, 6).

Figure 4 represents a model of the factors that may be involved in carrying out a system safety program. Minor

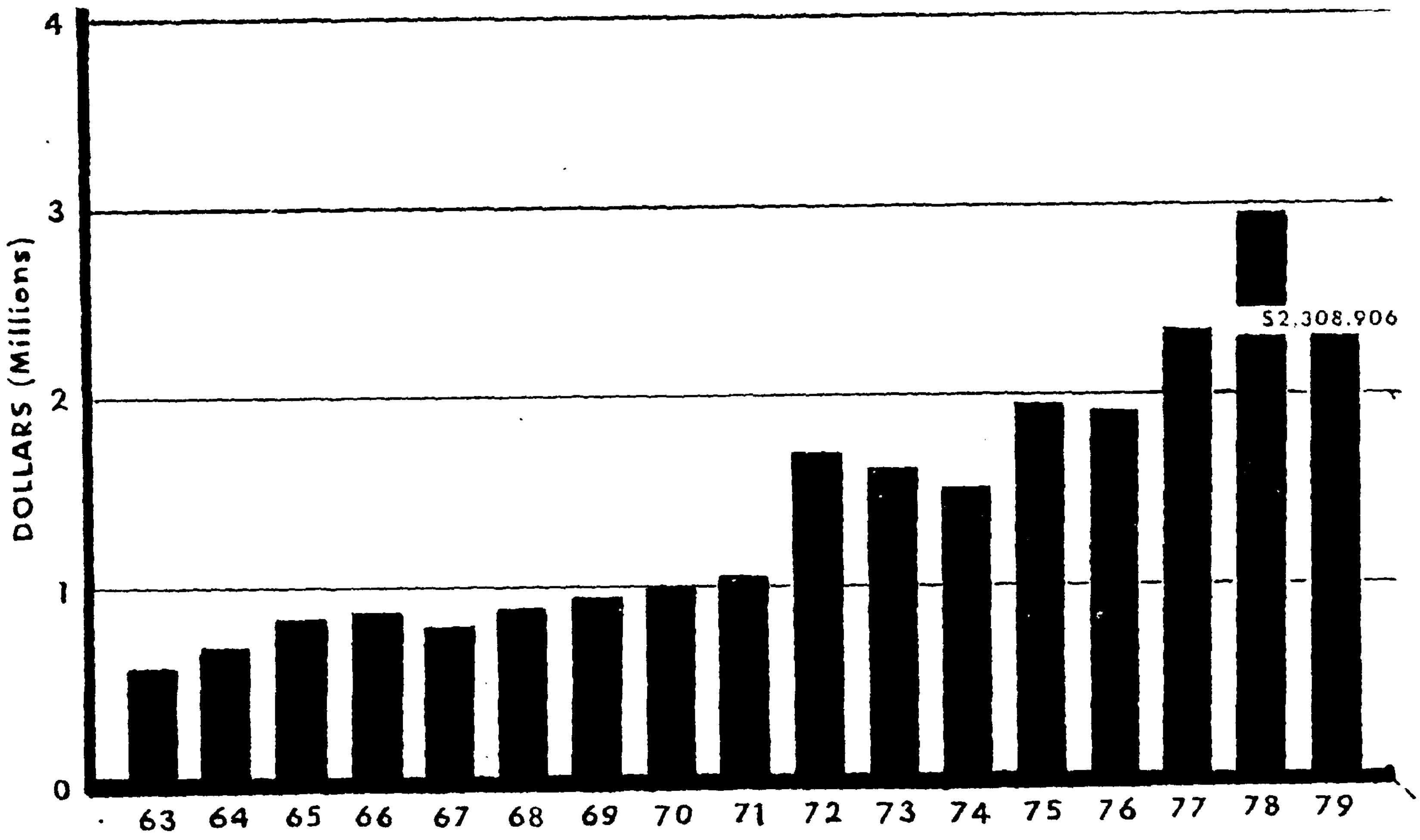


Figure 3. U.S. Navy/Marine Average Cost per Major Aircraft Accident (24th Annual Meeting of the Human Factors Society, Los Angeles, October 1980)

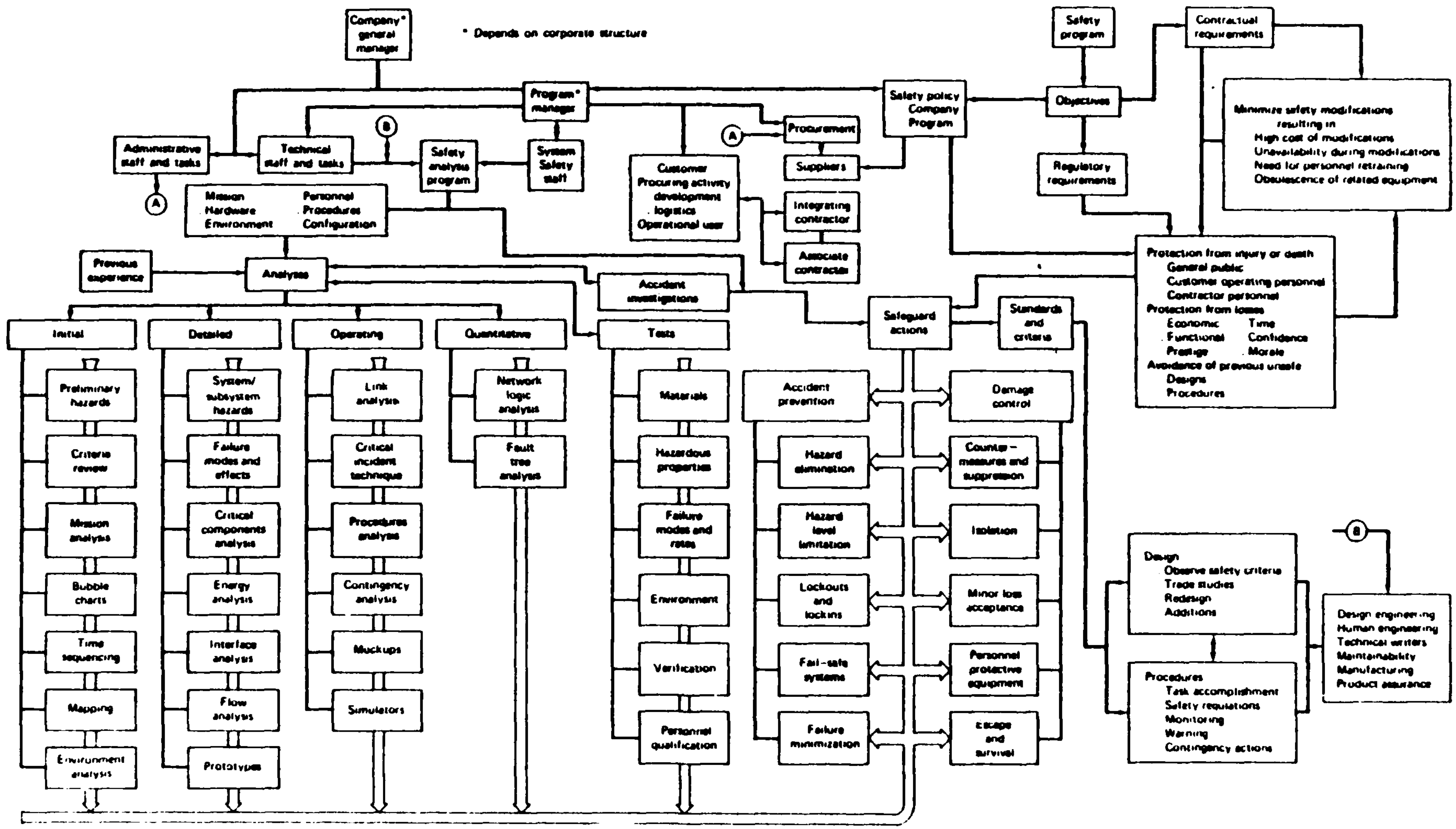


Figure 4. Safety Program Model (Hammer; Handbook of System and Product Safety, 1972, p. 36)

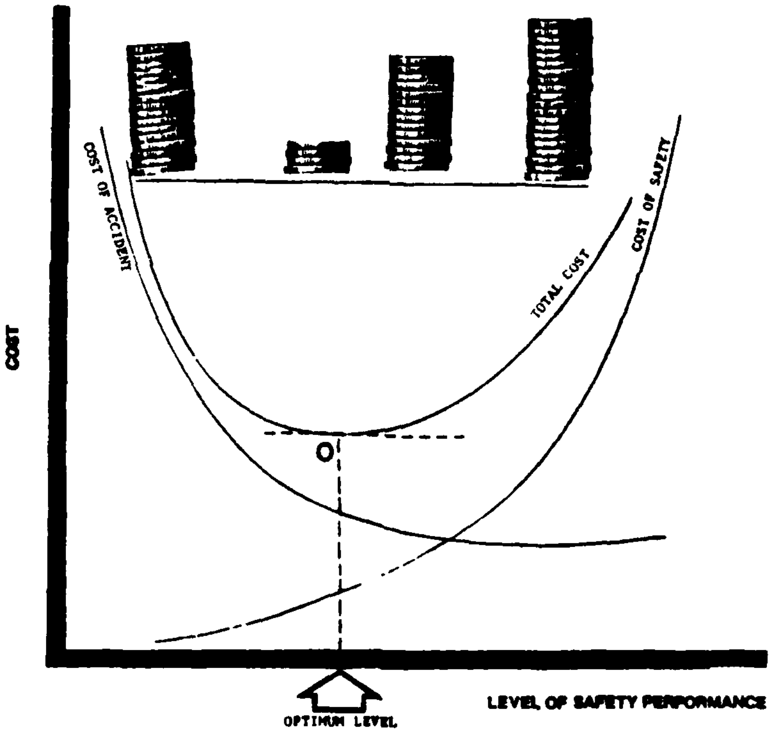


Figure 5. An Optimal Level of Safety Performance (Industrial Engineering, Jan. 1976, p. 20)

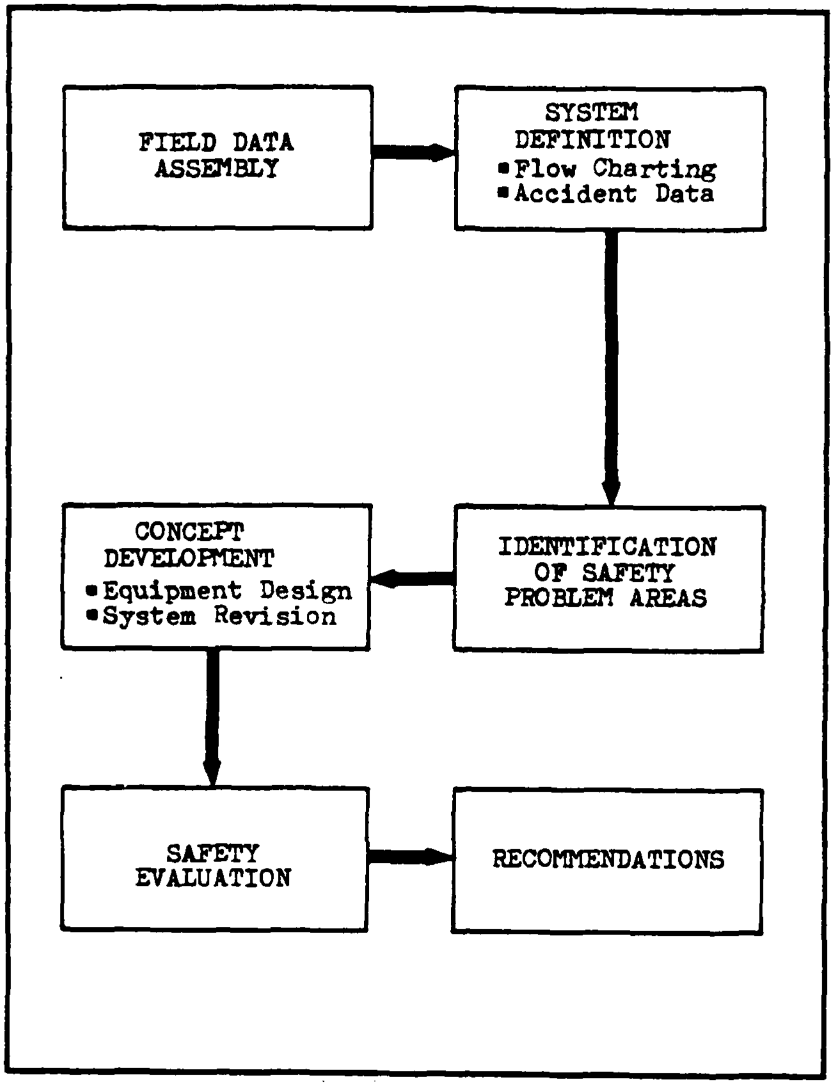


Figure 6. Safety Improvement Flow Chart (Industrial Engineering, March 1974, p. 9)

differences will exist in actual practice because of the different organizational structures. However, the model indicates broadly the process that takes place.

A safety program, regardless of its characteristics or goal, does cost money and require time. It is generally accepted that as the level of safety performance increases, the better will be the chances for reducing hazards, and consequently, the frequency as well as severity of accidents. Beyond a certain performance level, however, the expected reduction in hazards starts to taper off and will not be of appreciative magnitude to offset the cost associated with high levels of safety activities. This is explained well in Figure 5.

Figure 6 as presented in the overall safety improvement effort through the accidents reduction approach, includes the following basic steps.

a. Field data assembly.

In this step operating data are gathered on the system to be analyzed to: acquaint the analyst with system operating methods, procedures and equipment; and obtain operating data in the form of methods and time data for system operations. In addition, accident data are gathered to provide a basis for identifying accident problem areas and determining potential accident cost savings.

b. System definition.

Flow charting. Functional flow charts should be developed to define the system. The charts serve as a guide for project members, put them on the same level of thinking, and allow standard methods and procedure references that all understand.

The charts should have a numbering system by function to permit coding of accident data. The codes allow quick reference to what work function was being performed when an accident occurred, and are a means for computerized accident information storage and retrieval.

Accident data. All accident data gathered are defined/ coded by work function and hazards or causes assigned to accidents. Hazards definition is needed to indicate equipment and system shortcomings with regard to safety.

c. Identifying problem areas.

Once hazards and safe data have been gathered, they must then be examined for safety problem areas. The problem areas should be defined so that concepts may be readily developed.

d. Concept development.

Once safety problems have been defined, the next step is to develop concepts that will eliminate or protect against hazards and, as a result, reduce accidents.

e. Safety evaluation.

The effects on safety are determined by using the hazards exposure data and estimating the reduction in hazards exposure for all functions attributable to a new concept. The hazards exposure reduction is an engineering estimate made by comparing current machines/systems with those proposed, and noting by work function where hazards exposures have been increased or decreased and by how much. The reduction expected in accidents is proportional to the reduction in the hazard exposure.

f. Recommendations.

The last step is to consider evaluation results for concepts and alternatives and make a decision for further study, or choose the most attractive alternatives for design development.

There are certain fundamental concepts and methods that, if properly applied, can increase the probability of success. Accident prevention is a composite of many related functions, each of which must be given proper weight to assure a balanced and productive program. It may be considered a closed-loop system (Figure 7) comprising many feedback loops in which information is collected by the responsible agency, is appropriately processed, is systematically analyzed, and then is disseminated to those in a position to make use of the information. The results of this dissemination are reevaluated in the light of future accidents.

To put safety in its proper perspective, it must be first realized that safety and efficiency are products of each other. That is, the safe establishment is efficient. With this in mind, safety then becomes a management problem and not just the concern of the foreman or the supervisor.

Petersen (1978) suggests five basic principles of a safety management program. These are:

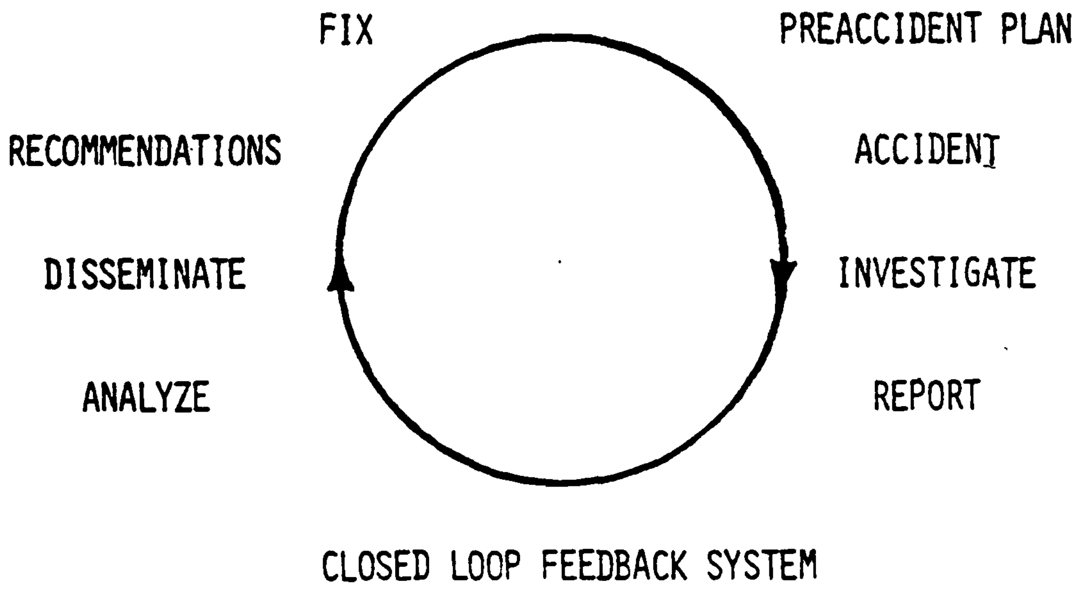


Figure 7. Organizational Approach to Safety (Zeller, 1978)

a. An unsafe act, an unsafe condition, and an accident are all symptoms of failure in the management system.

b. Certain circumstances are predictive of severity of accidents.

c. Safety should be managed like any other operational function.

d. An effective safety program will provide establishment of responsibility and accountability.

e. The function of safety is to locate and define the operational errors that allow accidents to occur. This function can be carried out in two ways: 1) by asking why accidents happen--searching for their root causes--and 2) by asking whether certain known effective controls are being utilized.

Now comes the problem of safety measurement. W. Tarrants (1979) discussed this problem as the problem that has existed since the very beginning of organized attempts to control accidents and their consequences. In its most elementary form, measurement has been defined as "the process of assigning numerals to objects according to rules" (Stevens, 1951). When we apply this definition in the safety field, we are quickly confronted with problems concerning what "objects" to measure and what "rules" to follow.

The progress and maturity of a science or technology are often judged by whatever success has been achieved in the use of measures. Measurement, perhaps more than any other single aspect, has been the principle stimulus of progress in all professional fields. Measurement is the backbone of any scientific approach to problem definition and solution. Without adequate measurement in the safety field we can not describe the safety state of our operations or determine whether or not our safety programs are really accomplishing anything. Sound measurement is an absolute prerequisite for control and both are necessary for prediction.

The present thesis effort will 1) perform a literature survey of the techniques to measure safety which are applicable to measurement of flight safety, 2) emphasize the importance of accident data collection for analyzing them, 3) refer to K.A.F. accident data currently collected whether they are applicable or not to measure flight safety, and finally

4) suggest methodology to collect data for applying each technique.

II. LITERATURE SURVEY

It has become apparent that there are many problems associated with defining a universal criterion for safety measurement and assessment. One of the chief concerns with the conventional standards is the emphasis on accident data. Many now recognize that this is more a reaction to existing problems than action toward prevention or control of future problems. Although experience can be a valuable teacher, accident experience points to needless loss, and too often doesn't give sufficient information for prevention.

Personal values present another problem in safety measurement and assessment. Safety attitudes are strongly dependent on the personal values of workers, line management, and corporate management; effective safety measurement techniques must be capable of addressing this behavioral aspect.

Applying statistical methods to the population of events related to accidents is another problem area. Predictions based on statistical analyses of accident data have been described as unreliable due to the combination of variables, rare events and small sample sizes. Often, attempts are made to by-pass this obstacle by combining nonsimilar events into a larger population universe.

Among the methods used for safety measurement are included statistical quality control techniques, system safety analysis techniques, critical incident technique, learning curve, frequency and severity rate, safety sampling, double average comparison technique. Here the author will describe the methods which are applicable to flight safety measurement.

A. CONTROL CHARTS

Greenberg (1971) suggests that the techniques of statistical quality control are ready-made tools for safety analysis because the safety professional has common problems with the quality inspector: both would like to be everywhere simultaneously to detect changes; and both have to apply some practical, effective approaches to their problems. Control charts are used for this purpose. According to Brown (1976), a control chart is a visual means by which an analyst judges whether a process is in control or not. The measurement plotted on the chart are those of any random variable. Hence the frequency and severity of accidents, as well as any other intermediate indicator of hazards, could be plotted. Judgments based upon these plots determine if the process is in control with respect to the random variable under consideration.

Figure 8 shows the typical layout of a control chart. The units of the random variable are given on the vertical scale, indicating that the height of the plotted point represents the value of the random variable for the indicated time period. The time scale, given by horizontal line shows when the value occurred.

Measurement of central tendency and spread define the expected concentration and range of the variable. Thus, if

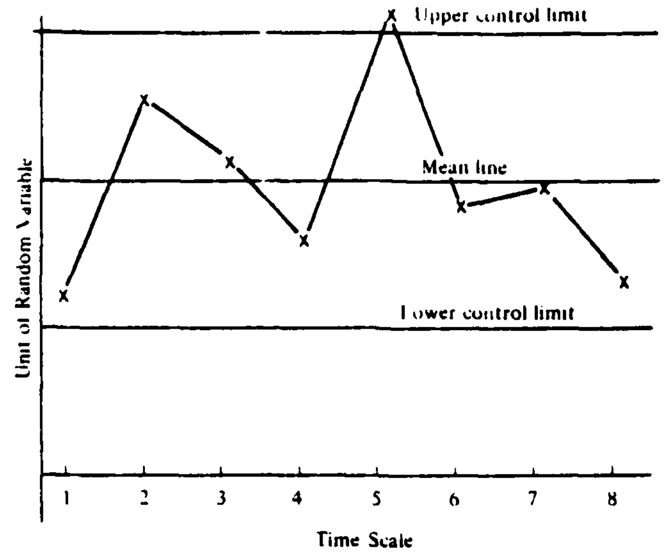


Figure 8. Sample Control Chart
(Brown, D.B. [1976], p. 230)

the variable behaves in a nonrandom way, we can conclude that an outside influence is affecting the random variable. The common way of identifying when this occurs is through the use of an upper and a lower control limit. These are generally placed at equal distances above and below the mean line.

The measured values as they are recorded in time are plotted as indicated in Figure 8. A point falling above or below the control limits, respectively, is indicative of an out-of-control situation, and assignable causes are generally sought. There are other indications of out-of-control situations, also. However, prior to discussing these, the means for obtaining the control limits will be given.

The procedures for setting control limits are essentially the same as those for setting the *acceptance* limits in a test of hypothesis. The first step involves the establishment of significance level α, that is, the probability of concluding that the process is out of control when in fact it is in control. If methods of identifying causes are expensive and the variable is not critical, a low probability can be tolerated. However, if an early indication of lack of control is necessary, then a high probability of this error should be specified. Once the value of α is determined, the next question involves the definition of control. Quite often the state "out of control" occurs in one direction only, that is, upper control limit would be required as it would in most cases of pollution measurements (Figure 9). Other monitoring of processes would require both an upper and a lower control limit.

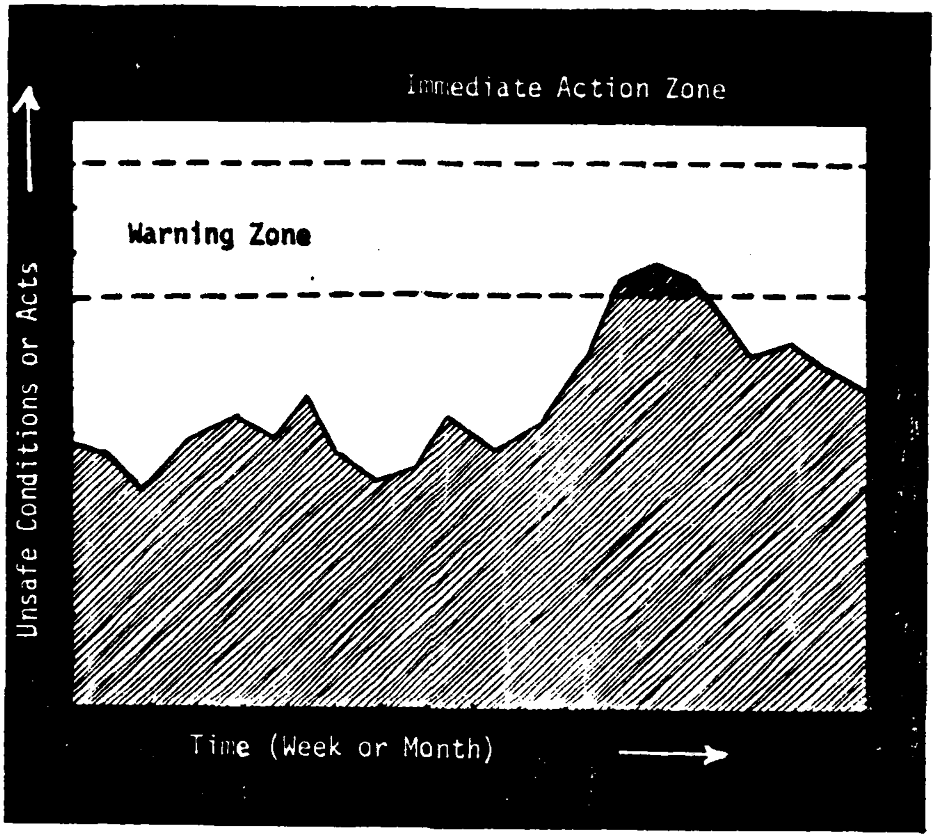


Figure 9. Sample of a Safety Control Chart Used in Statistics Approach to Safety Evaluation (Industrial Engineering, Dec. 1975, p. 20)

In either case, the value of α chosen will represent the total area of probability in the out-of-control portion of the chart. The upper and lower control limits are obtained depending upon the random variable, its distribution, and the value of α chosen.

Brown (1976) suggests in the following example that the frequency of accidents of a plant has a normal distribution with a mean of 6 and a standard deviation of 1.5. Frequencies for the first 6 months have been 4, 7, 5, 12, 8, and 6. Set up a monthly control chart for frequency. Allow for a .05 probability of calling a point out of control when it is not.

In this example "out of control" is strictly in terms of an upper limit. However, the analyst chooses to set up a lower limit to provide possible evidence of a lowering of the accident frequency. Thus the .05 probability will be divided, .025 above the upper limit and .025 below the lower limit. The upper limit becomes

$$\text{U.L.} = \bar{x} + Z_{.025}\,\sigma_x$$

$$= 6 + 1.96(1.5) = 8.94$$

and the lower limit is

$$\text{L.L.} = \bar{x} - z_{.025}\,\sigma_x$$

$$= 6 - 1.96(1.5) = 3.06$$

where

$$Z = \frac{x-\mu}{\sigma} \quad \text{(which "standardizes" any normally distributed random variable)}$$

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$

$$\sigma_x = \sqrt{\sigma_x^2} = \sqrt{(\textstyle\sum (x_i - \bar{x})^2)/n-1} = E[(x - \mu_x)^2]$$

$$\mu_x = E[X]$$

The control chart is given in Figure 10. The fourth month was obviously out of control, and assignable causes should be sought. In this example the assumption of normality should be tested since it does not hold generally.

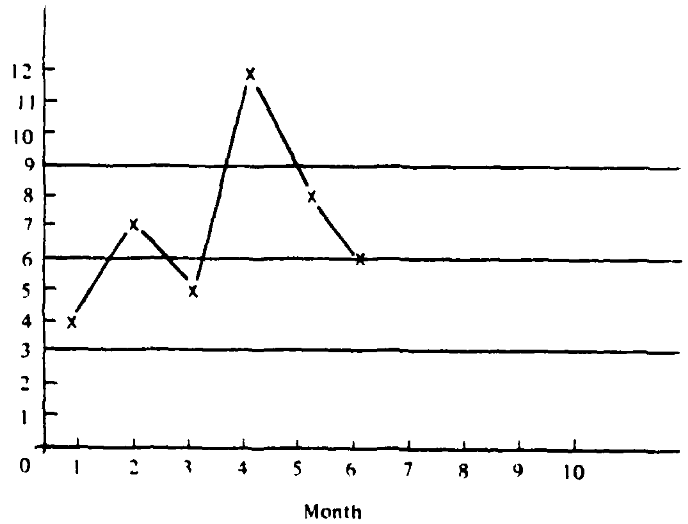


Figure 10. Control Chart for Example Described in Text (Brown, 1976, p. 231)

The construction of the chart is simply a matter of applying hypothesis testing on a continuous basis. The primary advantage is that continuous visual perception of the random variable is maintained. This continuous picture enables the analyst to make judgments not otherwise discernible. This is not limited to the upper and lower control limits demonstrated above. Other factors that the analyst can use as indicators of abnormal operational behavior include:

a. Several points (four or more) in a row on one side of the mean line. The probability of four consecutive points on one side is approximately $.5^4$, or .0625.

b. Identifiable cycles. Here two or three years of history may be required to identify a given month or other period of time when the operation acts in an irregular manner.

c. Several points in a row, either monotonically increasing or decreasing away from the mean line. The probability of this type of trend is difficult to establish. However, since these points are all on one side of the mean line, the probability will be considerably less than $.5^n$, where n is the number of points exhibiting this characteristic.

In quality-control situations, 3σ control limits are generally used, based on the 1-in-1000 value of α under the normal distribution assumption. The 2σ and 1σ lines may also be set up, however, to help the analyst identify other out-of-control indicators. For example, two points in a row outside of 2σ limits would have an approximate probability of $(.025)^2 = .000625$, which is about the same as the probability of one point outside 3σ limits, assuming normality. Although control charts for safety applications should not be restricted to the $\alpha = .001$ value, the concept of intermediate lines to identify irregularities is a good one.

B. SYSTEMS SAFETY ANALYSIS

To understand the systems safety analysis we should first have a clear picture of what a system is. Worick (1975) defines a system as an orderly arrangement of components which are interrelated and which act and interact to perform some task or function in a particular environment. The main points to keep in mind are that a system is defined in terms of a task or function, and that the components of a system are interrelated, that is, each part affects the others. The task or function which a system performs may be simple or complex. Sometimes it is convenient to break up a complex task into simpler tasks and consider subsystems of the larger system. Subsystems consist of part of the components of the overall system and perform a portion of the overall task (Figure 11). The components of a system can cover a wide range including machines, tools, material, environmental factors, people, documents (such as operating instructions, training manuals, or computer programs), and so on. As part of a system, the components usually complement each other but it is essential to recognize that a failure or malfunction of any component can affect the other components and thus degrade the performance of the task.

The sequential steps required in all system analyses (Figure 12) are:

a. Recognition that a problem exists and that the solution may be amenable to systems analysis techniques.

b. Definition of that problem in an appropriate form, including a definition of objectives, requirements, and constraints of times, resources, operational environment, social acceptability, etc.

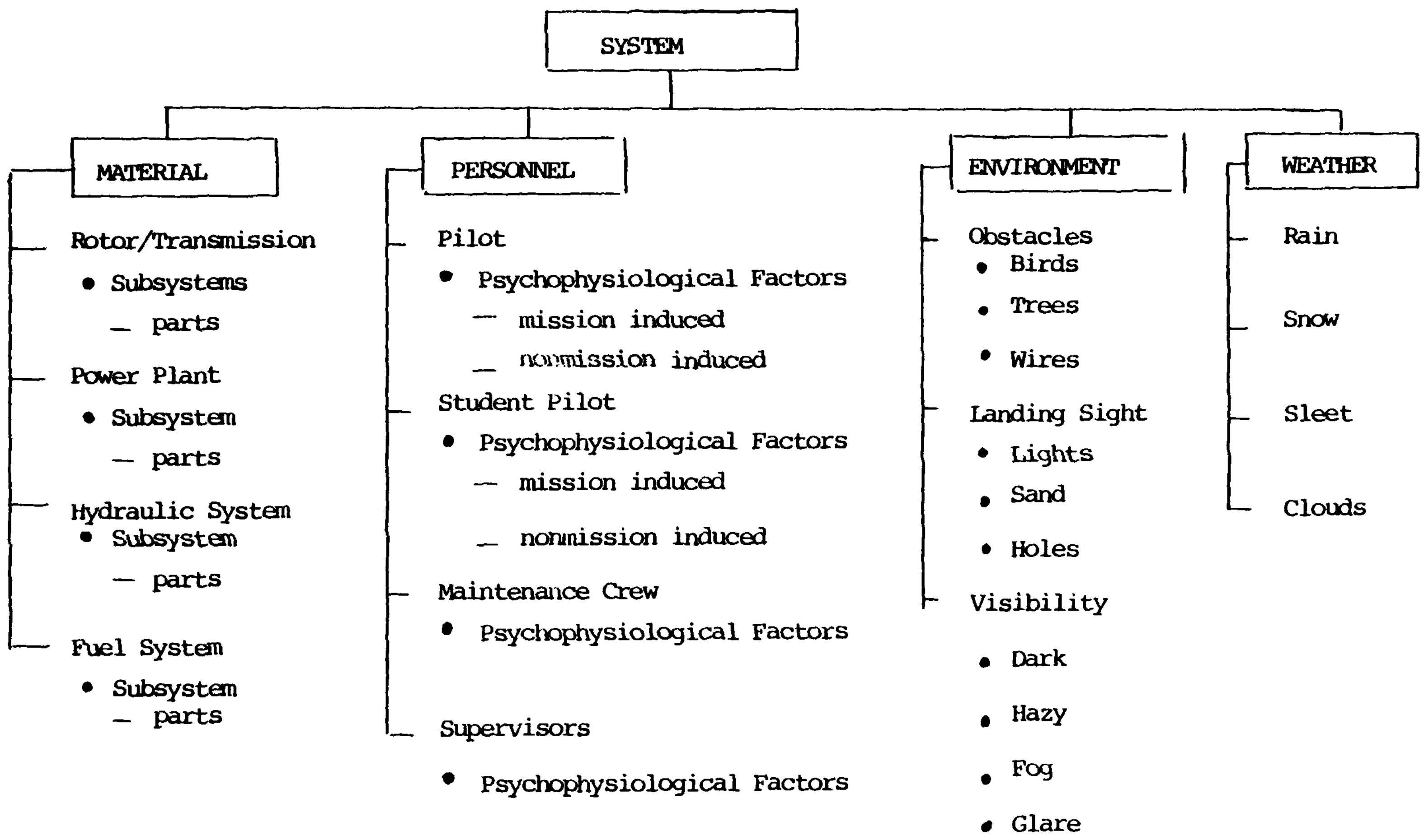


Figure 11. Example of System Elements in Aircraft Accidents (Kent J. Kogler [1976], p. 7)

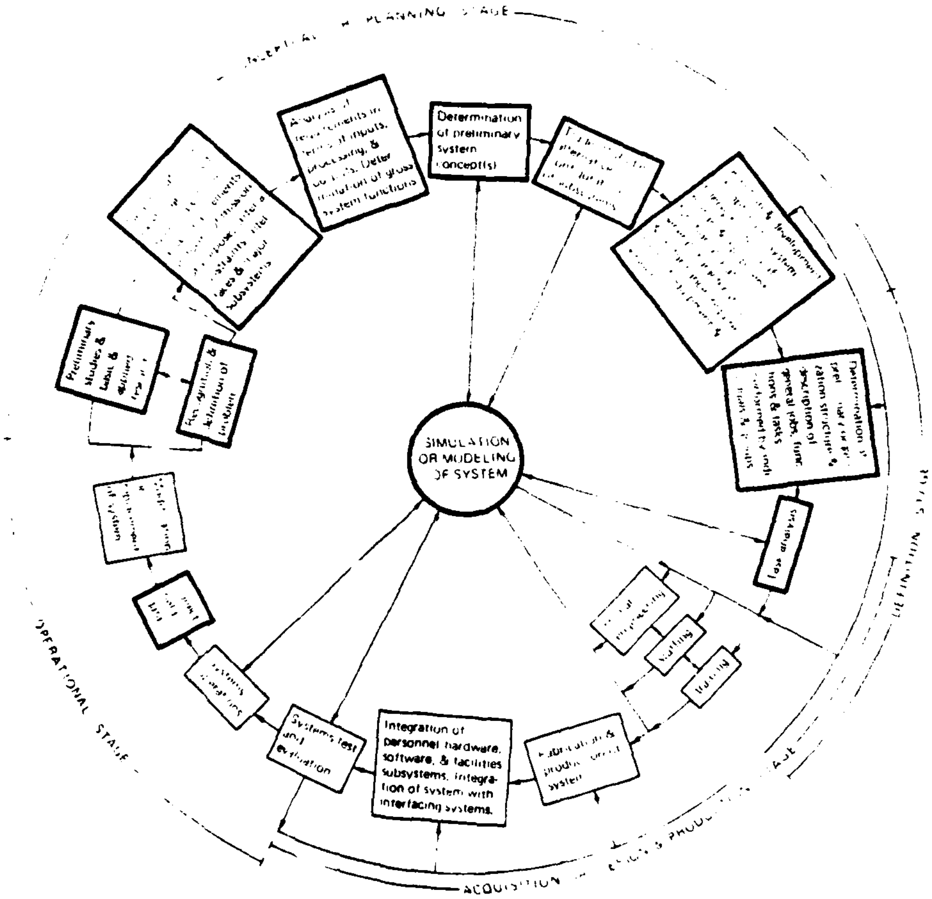


Figure 12. Systems Development Flow Diagram (System Psychology--DeGreene [1970], p. 84)

c. Definition of system itselft in terms of its hierarchical level, boundaries, interfaces, environments, functions, and constituent subsystems and their interactions, usually expressed in input/throughput/output terms. This iterative process begins with gross approximations and works toward minute preciseness, involving test and modification of the original concept. The result should be a conceptual model amenable to quantitative analysis.

d. Definition of performance criteria for the system as a whole, for the various levels of organization, and for the combination of its constituents.

e. Definition of alternative configurations and their evaluation in terms of costs, effectiveness, state of development, environmental constraints, etc.

f. Presentation of alternatives and tradeoff results to the user. A number of choices should be presented in order of preference.

g. Performance of ongoing, iterative engineering and human factors analyses during systems development.

h. Analyses of operational systems to gether basic performance data.

The importance of these preliminary steps cannot be overemphasized. As in any research, the analyst himself may introduce bias in the form of poor problem formulation, not understanding the system, or in not understanding the true role of analysis. In some cases, it may not be known until the system is complete whether the problem was defined correctly.

There are several methods which are used for the systems analysis techniques, but the author will describe here the fault tree and cost-effective analysis.

1. Fault Tree Analysis

Fault Tree Analysis (FTA) was developed mainly by engineers who studied engineering systems in great detail, with little or no contribution by mathematicians. A possible explanation given by R.E. Barlow (1975), J.B. Fussell (1975) and N.D. Singpurwalla (1975) is the fact that the construction of the fault tree, a basic step in fault tree analysis, requires an intimate knowledge of the manner in which a system is designed and operated. The mathematician's lack of familiarity with the operation of systems, and perhaps their preoccupation with mathematically well-defined problems, has deterred their interest in fault tree analysis.

Brown (1976) developed Fault Tree and cost/benefit analysis for choosing optimal safety alternatives. Brown shows how negative utility amounts can be assigned to all possible head events and the relevant possibilities multiplied by the negative utilities. The results, which are expected negative utility amounts, are called "measures of criticality".

Reductions in negative expected utility or criticality are considered to be quantitative expressions of benefits or effectiveness, and these are then related to costs to find the optimal combination of safety alternatives for the decision maker's cost-benefit trade-off function.

Using Brown's methodology the safety manager should first utilize the fault-tree analysis technique as a logical approach to identify the areas in a system that are most critical to safe operation.

According to R.E. Barlow (1975) and H.E. Lambert (1975), FTA is one of the principle methods of systems safety analysis. FTA evolved in the aerospace industry in the early 1960's. It was the result of a contract between the Air Force Ballistics Systems Division and Bell Telephone Laboratories for the study of inadvertent launch in the Minuteman ICBM (Delong, 1970). After initial work at Bell Telephone Laboratories, development of fault tree continued at the Boeing Company, where scientists devoted much effort to develop its procedures farther and became its foremost proponents. The principle of Boolean algebra (Appendix A) is applied for FTA.

Rogers (1971) has referred to the following six steps that were used in applying the technique to the Minuteman Program:

1. Define the undesired event.
2. Acquire complete understanding of the system.
3. Construct the fault tree diagram.
4. Collect quantitative data.
5. Evaluate fault tree probability.
6. Analyze computer results.

Undesired events requiring FTA are identified either by inductive analysis, such as a preliminary hazard analysis, or by intuition. These events are usually undesired system states that can occur as a result of subsystem functional faults.

FTA is a detailed deductive analysis that usually requires considerable system information. It can be a valuable design tool. It can identify potential accidents in a system design and can help to eliminate costly design changes and retrofits. FTA can also be a diagnostic tool. It can predict the most likely causes of system failure in the event of a system breakdown.

A major difficulty with quantitative fault tree evaluation is the lack of pertinent failure rate data. Even in cases where the data are goodk it is not clear that we can justify one system environment, data that were obtained in a different system environment. Nevertheless, quantitative evaluations are particularly valuable for comparing systems designs that have similar components. The results are not as sensitive to failure rate data as in an absolute determination of the system failure probability.

The goal of fault tree construction is to model the system conditions that can result in the undesired event. One of the advantages of manual fault tree construction is that it forces the analyst to understand the system thoroughly. Before the construction of a fault tree can proceed, the analyst must acquire a thorough understanding of the system. In fact, a system description should be part of the analysis documentation. The analyst must carefully define the undesired event under consideration, called the 'top or head event'.

a. Event Description

A fault tree is a model that graphically and logically represents the various combinations of possible events, both fault and normal, occurring in a system that leads to the top event. The term, event, denotes a dynamic change of state that occurs to a system element. System elements include hardware, software, human and environmental factors.

b. Event Symbols

The symbols shown in Figure 13 represent specific types of fault and normal events in FTA. The rectangle defines an event that is the output of a logic gate and is dependent on the type of logic gate and the inputs to the gate. The circle defines a basic inherent failure of a system element when operated within its design specifications. It is therefore a primary failure, and is also referred to as a generic failure. The diamond represents a failure, other than a primary failure that is purposely not developed further. The switch event represents an event that is expected to occur or to never occur because of design and normal conditions, such as a phase change in a system. The conditional input may be applied to any gate and describes a condition which must be present to produce the output. For example, an

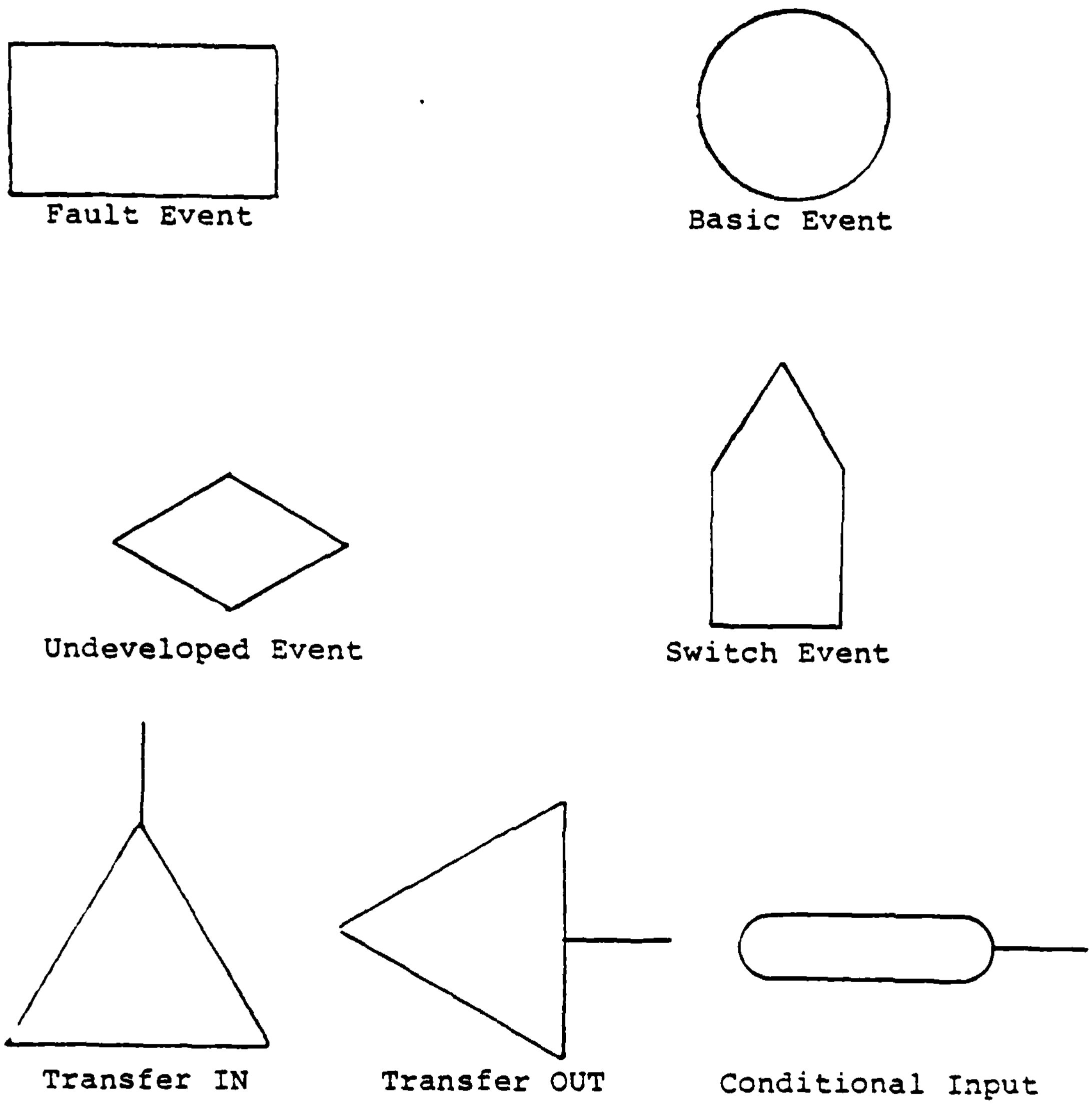


Figure 13. Event Symbols Used in Fault Tree Analysis (Brown, D.B. [1976], p. 158 and Rodgers, W.P. [1971], p. 41)

order sequence of the inputs to an AND GATE may be described as a condition input. The triangles are used as transfer symbols. A line from the apex indicates a transfer in, and a line from the side shows a transfer out.

c. Logic Gates

The fundamental logic gates for fault tree construction are the OR and the AND gates. The OR gate describes a situation where the output event will exist if one or more of the input events exist. The END gate describes the logical operation that requires the coexistence of all input events to produce the output event. the INHIBIT GATE describes the relationship between one fault and another. The input event causes the output event if the indicated condition is satisfied. If the condition involves a specific failure mode, it is represented by an oval. It is shown in a rectangle if the condition described is one that may exist anytime during the life of the system. The symbols for the logic gates are shown in Figure 14.

d. Construction Methodology

The fault tree is so structured that the sequences of events that lead to the undesired events are shown below the top event and are logically related to the undesired event by logical gates. The input events to each logic gate that are also outputs of other logic gates at a lower level are shown as rectangles. These events are developed further until the sequences of events lead to basic causes of interest,

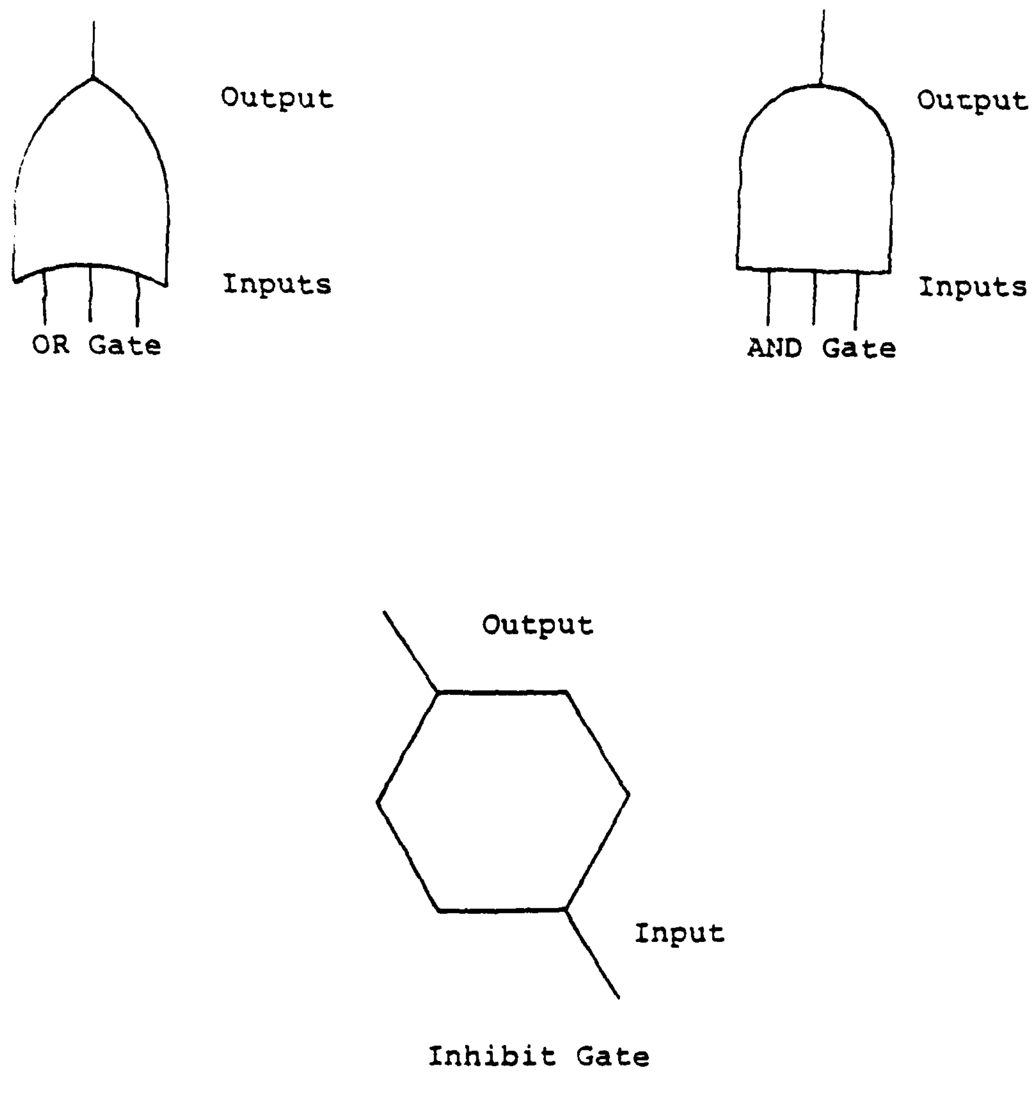


Figure 14. Symbols for Logic Gates Used in Fault Tree Analysis (Rodgets, W.P. [1971], p. 40)

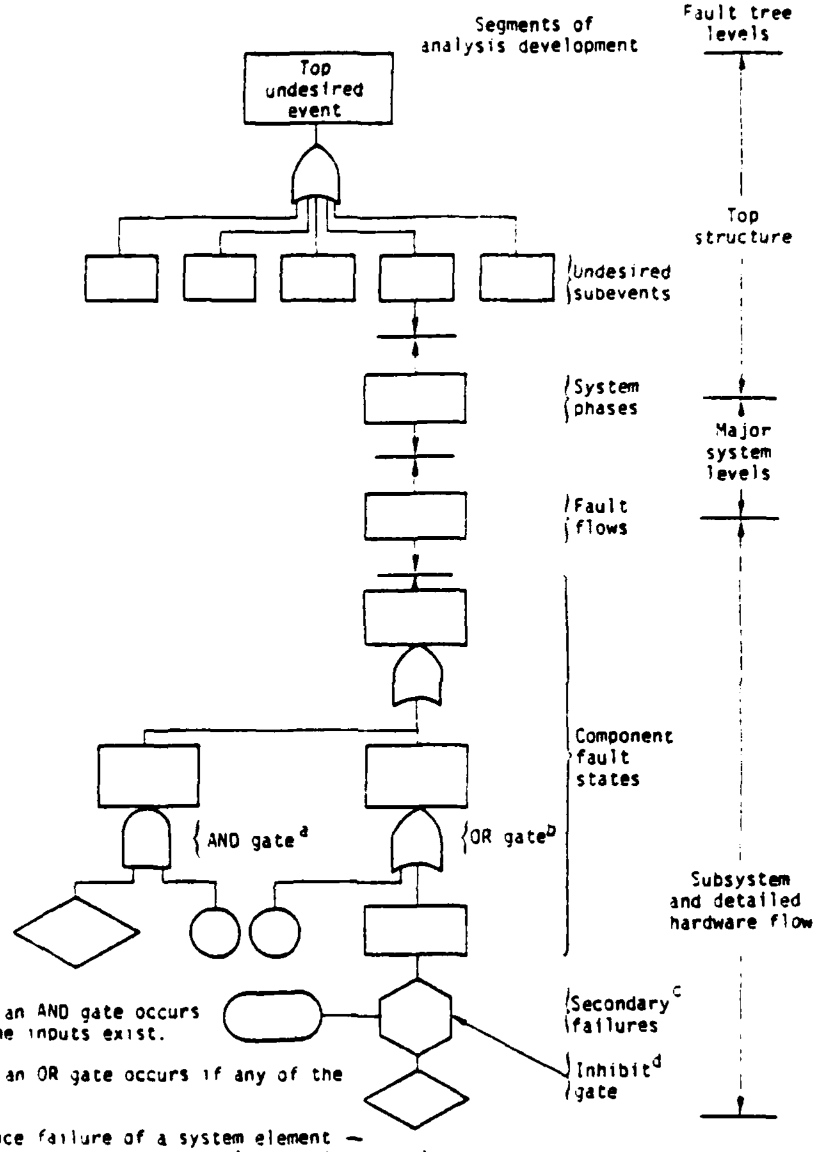
called "basic events". The basic events appear as circles and diamonds on the bottom of the fault tree and represent the limit of resolution of the fault tree. The structuring process is used to develop fault tree flows in a fault tree (Figure 15) when a system is examined on a functional basis, that is, when failures of system elements are considered. At this level, schematics, piping diagrams, process flow sheets, etc., are examined for cause and effect types of relationships to determine the subsystem and component fault states that can contribute to the occurrence of the undesired event.

e. Purpose of Fault Tree Construction

The fault tree, once constructed, serves as an *aid in determining the possible causes of an accident.* When properly used, the fault tree often leads to discovery of failure combinations which otherwise might not have been recognized as causes of the event being analyzed. The fault tree can be used as a visual tool in communicating and supporting decisions based on the analysis, such as determining the adequacy of a system design. The fault tree provides a convenient and efficient format helpful for either qualitative or quantitative evaluation of the fault tree, such as determination *of the probability of the occurrence of the top event.*

f. Evaluation of the Fault Tree

An objective of fault tree evaluation is to determine if there is an acceptable level of safety in the proposed



[a]The output of an AND gate occurs only if all the inputs exist.

[b]The output of an OR gate occurs if any of the inputs exist.

[c]Out-of-tolerance failure of a system element — failure due to excessive operational or environmental stress.

[d]An inhibit gate is a special case of the AND gate. The oval indicates a conditional event

Figure 15. Levels of Fault Tree Development (Barlow, R.E. and Lambert, H.E. [1975], p. 16)

system design, i.e., will the proposed design suitably minimize the probability of the occurrence of the top event. If the system design is found inadequate, then the design is upgraded by first identifying critical events (such as component failures) that significantly contribute to the top event. Cost constraints, contractual requirements, and other factors limit the design changes that can be made. Therefore, trade-off studies are necessary to determine what changes will be incorporated to reduce the effect of the critical events. When all design changes are made, the fault tree is re-evaluated to determine if the revised design provides an acceptable level of safety and/or reliability.

According to Brown (1976) the purpose of developing a fault tree and quantifying it is to effectively allocate the safety budget. To do this, the various alternative safety investments are considered in light of their effect upon the fault tree and the resulting head event. A measure of cost/benefit is then determined for use in decision making. Before completing the presentation of Brown's methodology some terminology as given by Brown will be introduced.

g. Cost

Cost is defined as the dollar outlay to pay for the incorporation of a device, method, procedure and so on (henceforth called a countermeasure) into the industrial system for a given unit period of exposure. Thus the cost of devices that must be periodically recharged and/or replaced is based on average costs for a given unit (e.g., a million man-hours (mmh) exposure period). Permanent fixtures, such as machine guards, can be prorated on the basis of the life of the machine. The cost of educational programs can be prorated, based upon their frequency. All countermeasures must, for comparison purposes, have a common denominator.

h. Benefit

Benefit is the negative utility reduction. Measure of benefit is the expected negative utility. There is a negative utility (or cost in terms of dollars and personal well-being) associated with accidents. This negative utility depends upon the severity of the accident.

The expected negative utility of the head event if it occurs can now be calculated by the following:

$$E = \sum_{i=1}^{N} P_i U_i$$

where:

P_i = the probability of occurrence of the i^{th} severity class given that the head event occurs,

N = the number of severity classes,

U_i = the negative utility associated with the i^{th} severity class.

An alternative method for calculating E would be more appropriate if the values of negative utility from a large number of past occurrences of the head event were measured directly. Thus the expected negative utility associated with the head event would be obtained from the arithmetic mean of these measurements:

$$E = \frac{\sum_{i=1}^{n} U_i}{n}$$

Both equations above are equivalent under the conditions that there are n severity classes (N = n) and that the probability of each severity class is equivalent ($P_i = \frac{1}{n}$). This occurs when each accident is considered as a unique situation.

i. Cost/Benefit

This term is a vague term used in describing a variety of applications. Here it is defined as the dollars spent per negative utility reduction.

j. Criticality

A system is defined as critical if there is any failure that will degrade the system beyond acceptable limits and create a safety hazard. An absolute measure of criticality associated with the head event can be obtained as

$$C = P \cdot E$$

where:

C = the expected negative utility associated with the head event in the given time or production unit.

P = the head event probability (in occurrence/mmh).

E = the expected negative utility (in dollars/occurrence or workday/occurrence etc.).

k. Determination of Head-Event Probability

The value of P can be obtained assuming that a proper unit of time or production has been determined to adequately define one trial.

$$P = \frac{N_h}{N_u}$$

where:

N_h = the number of occurrences of the head event in the trials given by the chosen time or production unit.

An alternative way to determine P is by using the fault tree end branch probabilities. This is necessary if the effect of alternative countermeasures is to be determined.

In the OR situation, any of the events will cause the subsequent event to occur and, therefore, assuming independence, the probability of occurrence of the subsequent event is given by

$$P_0 = 1 - \prod_{i=1}^{n} (1 - q_i)$$

where:

q_i = the probability of the i^{th} causal event.

n = the number of parallel branches.

In the AND situation, all the events must occur for the subsequent event to occur and, therefore, assuming independence, the probability of occurrence of the subsequent event is given by

$$P_A = \prod_{i=1}^{n} q_i$$

Through a reiterative process the probability of the head event can be determined from a knowledge of the probabilities of the branch events. This is the value of P which was given in the equation C = PE. A system modification will produce a change in this value of expected negative utility, thus providing the measure of benefit.

Brown (1976) gives various examples to demonstrate the entire procedure.

2. <u>Example</u>

Figure 16 is an example fault tree for developing the head event "Chip in Eye (Grinding)". This particular fault tree is to analyze the specific type of eye injury that might be caused by the grinding operation. Those who might have this accident fall into two mutually exclusive and all-encompassing categories: (1) operators and (2) nonoperators. Further, assume that the accident will not occur if adequate eye protection is worn. Therefore, the two events shown illustrate the first breakdown. The event "Operator Fails to Wear Safety Glasses" has an abbreviated label which, if spelled out in detail, would read "Operator Fails to Wear Safety Glasses and Is Injured by Chip in Eye."

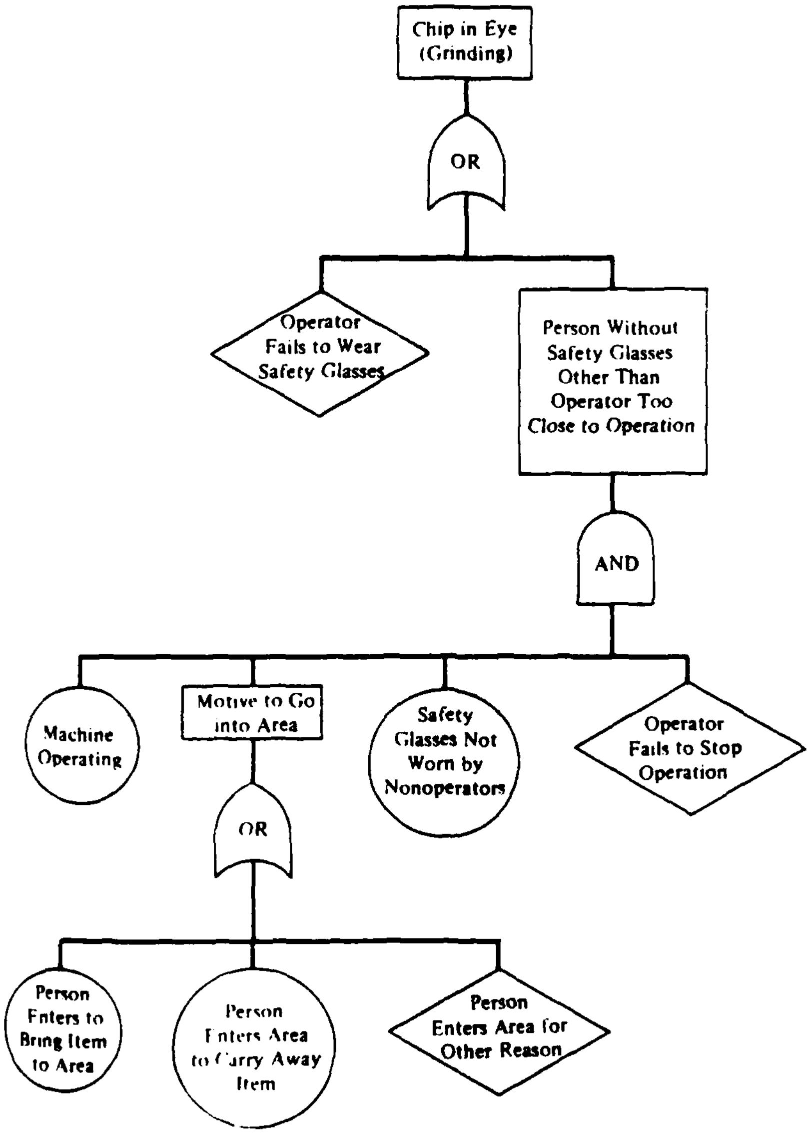


Figure 16. Fault Tree Illustrated

The AND relationship asks the question: "What must happen?" not "What could happen?" Four things must occur in order for the nonoperator to be injured in this way. These four are listed appropriately under the AND gate.

The event "Motive to Go into Area" analyzed into the specific reasons. This eventis used under OR gate here.

In Figure 17 the probabilities of occurrence are given for the end branch events for any million-man-hour period. Suppose that records show that in the past there have been 10 accidents of this type, of which 7 were First Aid, 2 were Temporary Total (man had to leave job), and one resulted in a Permanent Partial (caused permanent eye damage). An example of negativue utility schedule is given in Table I.

Table I

An Example of Negative Utility

Severity Classification	Severity	Negative Utility
1	First Aid	20
2	Temporary Total	345
3	Permanent Partial	2,500
4	Permanent Total (including fatalities)	21,000

*The value of negative utility need not be a dollar figure if other intangibles, such as social costs, are to be considered. For this example, however, First Aid was a dollar value per case estimated. All other figures are average costs per case given by the National Safety Council, 'Accident Facts', 1971.

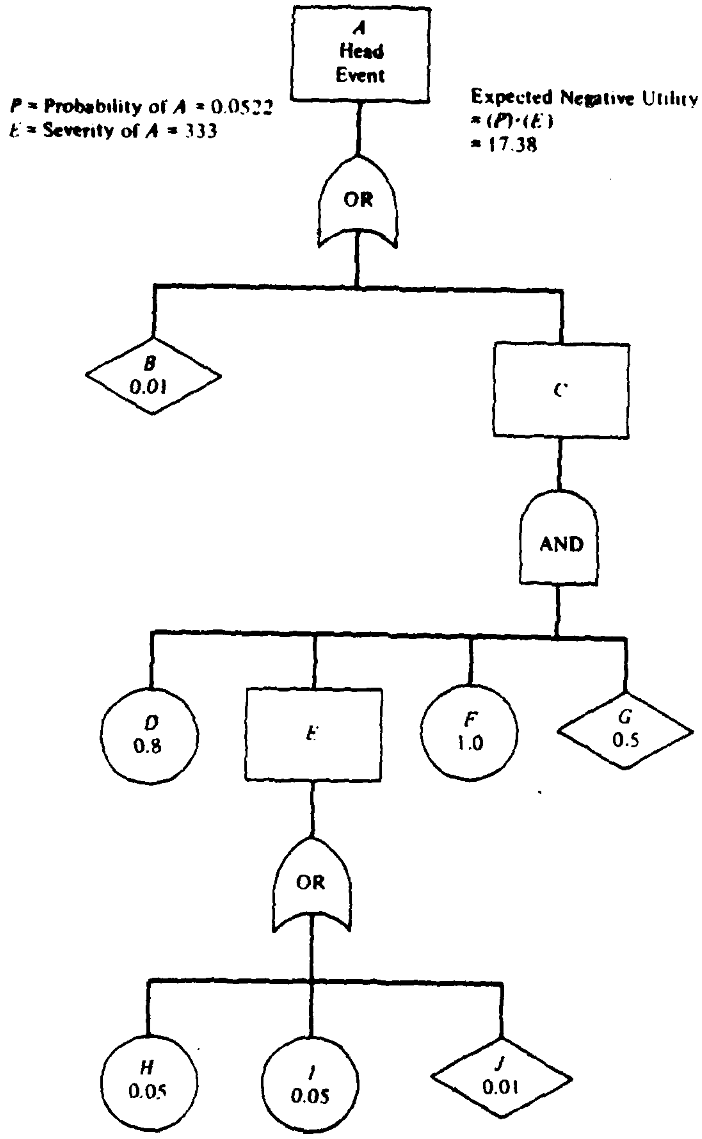


Figure 17. Fault Tree Illustrated the Probabilities Assigned

The expected negative utility of this accident is:

$$E = .7(20) + .2(345) + .1(2500) = 333$$

The probability of the OR gate given last:

$$P_A = 1 - (1 - 0.05)(1 - .5)(1 - .01) = 1 - .8935$$

$$= .1065$$

The probability of the AND gate is:

$$P_A = (.8)(.1065)(1)(.5) = .0426$$

The probability of the head event is:

$$P = 1 - (1 - .01)(1 - .0426) = 1 - (.99)(.9574)$$

$$= .0522$$

This is the probability of occurrence of the head event, in any million manhours of exposure.

The criticality associated with the head event is:

$$C = P \cdot E = (.0522)(333) = 17.38$$

This example will be pursued a bit further to determine how modifications on the fault tree are handled. If money is spent to improve the safety of this system, one or more of the basic event probabilities in the fault tree should be reduced or else the expected severity should be reduced. If not, either the expenditure should not be made, or else the fault tree is incorrect. A reduction in the basic event probabilities will always reduce the probability of the head event, P, and therefore it will also reduce the criticality, C, of the event. The amount by which the criticality is reduced will provide a measure of benefit for the change that was made. Hence a measure of benefit can be estimated for any safety investment.

Consider three proposed countermeasures to reduce the probability of the head event "Grinding Chip in Eye" originally presented in Figure 16. Assume the three alternatives were given as in Table II.

Table II

Three Proposed Countermeasures and Associated Cost

Alternative	Description	Prorated Cost/mmh	Effect
1	Ensure that operator stops operation whenever anyone enters area	$25	Reduce probability of event G to .05
2	Move storage area away from grinding area	$15	Reduce probability events H and I to zero
3	Both 1 and 2	$30	Same effects as both 1 and 2

Let's calculate the probability of head event, criticality, savings, and cost/benefit.

Alternative 1

$$P = 1 - (1 - 0.01)(1 - (0.8)(.1065)(1.0)(0.05)$$

$$= 1 - 0.9858 = 0.0142$$

$$C = P \cdot E = (0.0142)(333) = 4.73$$

$$\text{Savings} = 17.38 - 4.73 = 12.65$$

$$\text{Cost/Benefit} = 25/12.65 = 1.98$$

Alternative 2

$$P = 1 - (1 - 0.01)(1 - (0.8)(1 - (1-0)(1-0)(1-0.01))(1.0)(0.5))$$

$$= 1 - 0.986 = 0.014$$

$$C = (0.014)(333) = 4.66$$

$$\text{Savings} = 17.38 - 4.66 = 12.72$$

$$\text{Cost/Benefit} = 15/12.72 = 1.18$$

Alternative 3

$$P = 1 - (1 - 0.01)(1 - (0.8)(1 - (1-0)(1-0)(1-0.01))(1.0)(0.05))$$

$$= 1 - 0.9896 = 0.0104$$

$$C = (0.0104)(333) = 3.46$$

$$\text{Savings} = 17.38 - 3.46 = 13.92$$

$$\text{Cost/Benefit} = 30/13.92 = 2.16.$$

Summary for alternatives are shown in Table III.

Table III

Three Alternative Cost/Benefit Analyses

Alternative	Cost	Original Criticality	New Criticality	Benefit	Cost/Benefit
1	$25	17.38	4.73	12.65	1.98
2	$15	17.38	4.66	12.72	1.18
3	$30	17.38	3.46	13.92	2.16

The best investment is the one with the lowest cost/benefit figure. Alternative 2 is superior to the others in terms of cost/benefit.

C. CRITICAL INCIDENT TECHNIQUE (CIT)

This technique is widely used as a method of discovering and attempting to reduce or control hazardous situations before accidents occur. CIT examines previously experienced difficulties by interviewing persons involved. It is based on collecting information on hazards, near misses, and unsafe conditions and practices from operationally experienced personnel. It can be used beneficially to investigate man-machine relationships in past or existing systems and to use the information learned during the development of new systems, or for the modification and improvement of those already in existence. The technique consists of interviewing personnel regarding involvements in accidents or near accidents; difficulties, errors, and mistakes in operations; and conditions that could cause mishaps. The surveys generally request the persons interviewed to include their own experiences and also experiences of other personnel whom they have actually observed. The person is asked to describe all near misses or critical mishaps that he can recall.

In effect, the CIT accomplishes the same end result as an accident investigation: identification through personal involvement of a hazard that has or could result in injury or damage. When the witnesses who observed a mishap or near miss, but were not participants, are added to those who were involved, an extremely large population is available from which information on accident causes can be derived.

Even isolated incidents reported by the technique can be investigated to determine whether corrective action is necessary or advantageous. However, when a large number of persons are interviewed regarding similar types of equipment or operations, similarities begin to appear in reports of hazards and near misses. Where these indicate deficiencies, difficulties, or other inadequacies, they can be accepted as indicators of areas in which improvements are necessary in the design of a product or system.

This technique provides a source of data on errors that contribute to critical and catastrophic accidents, and obtains information directly from operators, who are less reluctant to admit errors in nonaccident situations than in accident situations. The CIT has been used in evaluation of aircraft pilot safety and has proven beneficial as a qualitative safety technique.

Fitts and Jones (1947) used this technique very effectively after World War II when they conducted interviews with Air Corps pilots on errors made in operating aircraft controls and in reading aircraft instruments. Figure 18 indicates the classifications of 460 pilot errors made in operating aircraft controls. Over 80 percent of the errors reported can be considered as errors of design: design of controls, their arrangements, and their locations.

Fitts and Jones also made numerous recommendations for changes that would reduce human error, improve controls, and increase system effectiveness. These recommendations, many of which were incorporated in later aircraft and in human engineering standards, are quoted here to illustrate benefits that can be generated by this technique as a method of developing accident prevention measures:

a. More than half of all errors in operating cockpit controls can be attributed directly or indirectly to lack of uniformity in the location and mode of operation of controls.

b. Substitution errors can be reduced by (a) uniform pattern arrangement of controls; (b) shape-coding of control knobs; (c) warning lights inside the appropriate feathering button; and (d) adequate separation of controls.

c. Adjustment errors can be reduced by (a) automatic fuel flow control; (b) simplified one-step operation of wheels and

		No. of Errors	Percent Errors
1	SUBSTITUTION ERRORS confusing one control with another, or failing to identify a control when it was needed		
a	Using the wrong throttle quadrant control (confusing mixture, prop pitch, throttle, etc)	89	19
b	Confusing flap and wheel controls	72	16
c	Operating a control for the wrong engine (feathering button, ignition, mixture, prop pitch, throttle, etc.)	38	8
d	Failing to identify the landing light switch or confusing it with some other control	11	2
e	Confusing other controls (alarm bell, bomb-bay door, carburetor heat, cockpit heater, droppable gas tanks, emergency bomb release, engine heat, intercooler, oil bypass, oil coller parking brake, pitot heat, radio tuning control, salvo switch, trim tab, wobble pump)	21	5
	TOTAL	229	50
2	ADJUSTMENT ERRORS operating a control too slowly or too rapidly, moving a switch to the wrong position, or following the wrong sequence in operating several controls		
a	Turning fuel selector switch to the wrong tank	19	4
b	Following wrong sequence in raising or lowering wheels	18	4
c	Failing to obtain desired flap setting	17	4
d	Adding power too suddenly without proper change in trim	9	2
e	Failing to lock or unlock throttles properly	5	1
f	Failing to roll in trim fast enough	4	1
g.	Failing to adjust other controls properly	11	2
	TOTAL	83	18
3	FORGETTING ERRORS. failing to check, unlock, or use a control at the proper time		
a.	Taking off with flight controls locked (aileron, elevator, rudder, or all controls locked)	16	4
b	Forgetting generator or magneto switch	14	3
c.	Forgetting to make proper engine or propeller control adjustments (mixture, prop pitch, etc.)	11	2
d.	Forgetting to lower, lock or check landing gear	7	2
e.	Taking off with wrong trim settings	6	1
f	Taking off without removing pitot cover	4	1
g.	Forgetting to operate other controls (bomb-bay doors, bomb-rocket selector switch, coolant shutter, flaps, auxiliary fuel pump, fuel selector, hydraulic selector, lights, PDI switch, pitot heat, tail wheel lock)	25	5
	TOTAL	83	18
4	REVERSAL ERRORS moving a control in a direction opposite to that necessary to produce a desired result		
a	Making reversed trim correction	8	2
b	Making reversed wing flap adjustment	6	1
c	Making reversed movement of an engine or propellor control (mixture, prop pitch, etc.)	6	1
d	Making reversed movement of some other control	7	2
	TOTAL	27	6
5	UNINTENTIONAL ACTIVATION inadvertently operating a control without being aware of it (Brakes, carburetor heat, cowl flaps, generator, ignition, ignition, inverter, landing gear, lights, master switch, pitot heat, radio supercharger)	24	5
6	UNABLE TO REACH A CONTROL accident or near accident resulting from "putting head in cockpit" to grasp a control, or inability to reach a control at all (Carburetor heat, fuel selector, hydraulic switch, landing gear, nose wheel crank, rudders)	14	3

Figure 18. Classification of 460 Errors Made by Pilots in Operating Aircraft Controls (Hammer, 1972, p. 189)

flaps; (c) easily accessible and continuously operable trim controls; and (d) improved throttle locks.

d. Forgetting errors can be eliminated almost entirely by adherence to uniform and "natural" directions of control movement.

e. Unintentional activation of controls can be remedied by application of existing anthropometric data on body size and use of a maximum reaching distance of 28 inches from the shoulder for all controls used during critical procedures.

The CIT procedure was described by Tarrants as carried out at one plant of the Westinghouse Company. The steps may be summarized as follows:

a. A group of employees with previous experience and involvement in manufacturing processes and equipment was selected. Each person included was listed according to various factors to produce as wide a range of experience as possible. Representatives were selected randomly from each factor group.

b. The participants were interviewed and informed of the study and its objectives. They were given an opportunity to withdraw from participation.

c. At the end of the interview the participant was given a copy of the statement on the study and its objectives and a list of typical incidents gathered at other plants. This procedure was to stimulate the recall process.

d. Participants were asked to describe any incidents that they could recall, whether or not they had resulted in injury or property damage. They were asked whether they recalled any incident similar to those that had occurred at other plants, as described on the list they had been provided.

e. Questioning was carried on until human errors or unsafe conditions in any recalled incident could be described.

The 20 participants related 389 incidents of 117 different types. Over 50 percent more potential accident causes were found by this method than had been identified from accident records. One participant estimated that almost 70 percent of the problems reported occurred every day, indicating an almost constant exposure to danger. Once a potential accident has been reported, the hazards are corrected so that a real accident will not occur. As these hazards are eliminated or reduced so should accident frequency and severity rates.

The major deficiency of this method is that its effectiveness will be dependent upon all employees reporting those potential accidents (incidents) in which they are involved. Usually employees will be reluctant to do so. They are worried about their supervisors attitude, their own personal records and/or spoiling the company's safety record. Thus data with some degree of bias are introduced.

III. STATEMENT OF PROBLEM

Through the literature survey, several methods among the existing safety measurement techniques have been discussed for measurement of flight safety. From the above discussion it is apparent that the measurement of flight safety is an area for research and development which will allow major improvement in overall flight safety programs.

A most important aspect in the development of an effective safety program is collection and evaluation of data. The primary goal of any safety program is to prevent accidents. Accident prevention is best pursued within the framework of a systematic program. Detailed and well-selected collection of factual data is the first step in the development of an effective safety effort. By means of an overall evaluation of safety by analysis and dissemination of this data, accidents can be predicted and prevented.

The Korean Air Force is currently collecting data on aircraft accidents. Data categories collected are as follows.

a. Accident rate and flight time per model and year

b. Total accident rate, pilot and aircraft loss per year

c. Accidents by general factors (pilot, maintenance, material, supervisor, etc.)

d. Accidents in detail per factors (e.g., pilot factor: spin, disorientation, unusual, air collision, etc.)

e. Major accidents per flight time (e.g., 400 ~ 500 hrs: 8, 900 ~ 1000 hrs: 4, 1700 ~ 1800 hrs: 1, etc.)

f. Major accidents per flight phases (take off, climb, in flight, Let Down, landing)

g. Major accidents per missions (Air to Air, Air to Ground, Instrument Flying, etc.)

h. Major accidents per rank

i. Aircraft accident cost.

Many of the data categories listed above are useful and lend themselves to analysis (Items a, b, e). There are, however, some major deficiencies in data being collected by the Korean Air Force. From the accident prevention viewpoint and for the analysis of pilot error, it would be better to categorize the pilot errors of item c as follows:

a. Design-induced pilot factor (e.g., instruments that can not be seen properly because of their location).

b. Operations-induced pilot factor (e.g., air traffic control terminology).

c. Environment-influenced pilot factor (e.g., weather phenomena such as fog or thunderstorms).

d. Innate pilot factor (e.g., poor technique, misuse of controls, medical and psychological conditions).

Specifically, the data of items g and h are inadequate. For example, item g must include flight time or sorties. That is, accident rate must be calculated for each mission. Item h must consider the total flight time and pilots of each rank.

For example, suppose the cumulative number of pilots, flight time, and accidents for 10 years are shown in Table IV.

Table IV

Example Data for Ranks by Pilots, Flight Time and Accidents

Rank	2nd Lt.	1st Lt.	Capt.	Maj.	Lt. Col.
pilots	400	1,000	1,500	800	300
flight time	40,000	150,000	450,000	160,000	30,000
accidents	3	18	19	9	9

Then,

$$\text{Accident rate} = \frac{(\text{Number of pilots in each rank/total pilots}) \times \text{Accidents}\ 100,000}{\text{Flight time of each rank}}$$

$$\text{Total pilots} = 400 + 1,000 + 1,500 + 800 + 300 = 4,000$$

$$\therefore \text{Accident rate of 2nd Lt.} = \frac{(400/4000) \times 3 \times 100,000}{40,000} = .75$$

By the same formula, accident rates of 1st Lt., Capt., Maj., and Lt. Col., are 3.0, 1.58, 1.13, and 2.25.

From the data collected above we can only use control chart techniques because the data was not collected in detail. But the problem is that it is difficult to evaluate the overall safety effectiveness by this method because the control chart uses only the frequency or severity of accidents vs.

time (year, month, or week). Accidents must be considered as multiple causation events, i.e., rarely is a single factor solely responsible for the event.

The present thesis effort has been designed to examine data currently collected by the K.A.F. and make recommendations which will improve data collection procedures and subsequent analysis.

IV. APPROACH TO MEASUREMENT OF FLIGHT SAFETY

Several measurement techniques applicable to flight safety were presented in the literature survey. The problem is how should the data be collected to efficiently apply such measurement techniques? The author will present several methodologies to collect and apply data.

A. CONTROL CHARTS

The primary objective of this method is to show comparisons among accidents which occurred in a given period and to visually indicate out of control situations by plotting frequency of accidents vs. time (year, month, or week) and upper/lower control limits. A point falling above or below the control limits, respectively, is indicative of an out-of-control situation, and assignable causes are generally sought. To measure flight safety, we actually need only the upper control limit.

It is easy to collect these data. The K.A.F. does, in fact, collect monthly and yearly aircraft accident data. In addition, it may be advantageous to add daily and weekly data to monthly and yearly statistics.

Example

1. Data for accident rate (major, minor, or major + minor) per week (given period).

2. Pilot loss rate per year, month.

If the above data was collected, it would be possible to determine trends of accidents on a daily basis. In particular, we could analyze the accident factors (pilot error, material failure, supervisor, maintenance, environment) from item 1 by observing the upper control limit zone.

Analysis of Existing Data

The aircraft accident rate of the K.A.F. is as in Table V.

Table V

K.A.F. Accident Rate by Year

Year	70	71	72	73	74	75	76	77	78	79
Accident rate	10.8	7.6	7.3	9.7	9.5	5.7	5.0	1.4	5.6	4.2

Then the control chart of this data is shown in Figure 19.

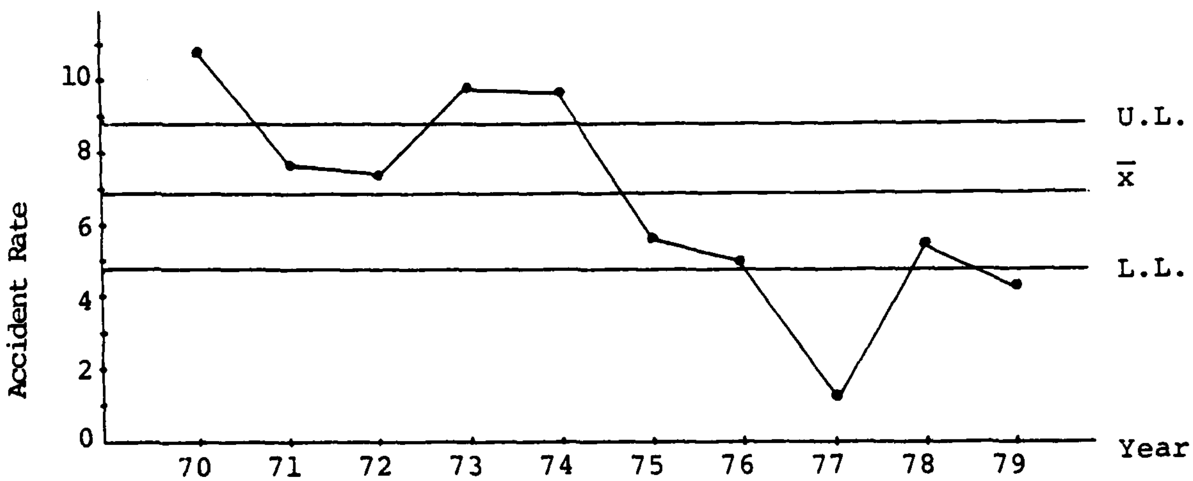


Figure 19. Control Chart Applied to K.A.F. Data

From the above data,

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} = \frac{66.8}{10} = 6.68$$

$$S = \sqrt{[\sum x_i^2 - (\sum x_i)^2/n]/n-1} = 2.87$$

The t distribution is used. For $\alpha = 0.05$,

$$\text{U.L.} = \bar{x} + t_{n-1,1-\frac{\alpha}{2}} \frac{S}{\sqrt{n}} = 6.68 + t_{9,.975} \frac{2.87}{\sqrt{10}}$$

$$= 6.68 + 2.262 \times \frac{2.87}{\sqrt{10}} = 8.73$$

$$\text{L.L.} = \bar{x} - t_{n-1,1-\frac{\alpha}{2}} \frac{S}{\sqrt{n}} = 6.68 - 2.262 \times \frac{2.87}{\sqrt{10}}$$

$$= 4.63$$

The accidents of 70, 73, and 74 are out of the control limit. So we have to analyze the accident causes of these years to prevent or reduce accidents in the future. Also we have to prepare accident prevention program according to the outcome of analysis.

Let's take $\alpha = .01$.

$$\text{U.L.} = \bar{x} + t_{n-1,1-\frac{\alpha}{2}} \cdot \frac{S}{\sqrt{n}} = 6.68 + t_{9,.995} \frac{2.87}{\sqrt{10}}$$

$$= 6.68 + 3.25 \times \frac{2.87}{\sqrt{10}} = 9.63$$

$$L.L. = \bar{x} - t_{n-1,1-\frac{\alpha}{2}} \cdot \frac{S}{\sqrt{n}} = 6.68 - 3.25 \times \frac{2.87}{\sqrt{10}}$$

$$= 3.73$$

The accidents of 70 and 73 year are yet out of control limit. The control chart is almost the same as test of hypothesis.

$$H_0: \ \mu = \mu_0$$

$$H_1: \ \mu > \mu_0$$

The acceptance and rejection regions are illustrated in Figure 20. Here assume that the hypothesis is true and use the value of α to determine the "cut-off" point for acceptance or rejection. α is the probability of rejection given that the hypothesis H_0 is true.

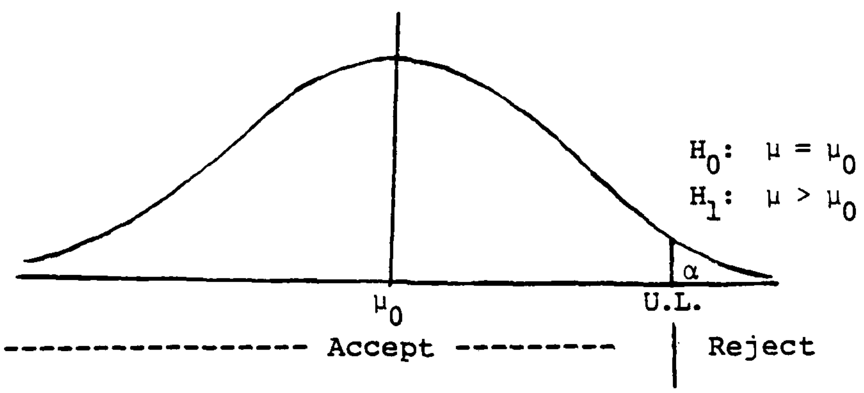


Figure 20. Acceptance and Rejection Region

For H_0: $\mu = \mu_0$ and H_1: $\mu > \mu_0$, assuming that H_0 is true, the distribution is centered at μ_0. Now according to the definition of α we will accept α probability of rejecting H_0 even though it is true.

Example

Aircraft accident rate of the K.A.F. was supposed to be reduced up to average 5.0 from 1970 to 1979. Was the accident level reduced significantly?

H_0: $\mu = \mu_0$ (Accident level was reduced significantly)

H_1: $\mu > \mu_0$ (Accident level was not reduced significantly)

Then from accident data given above:

$$\begin{aligned} \text{U.L.} &= \mu_0 + t_{n-1,1-\alpha} \cdot \frac{S}{\sqrt{n}} \\ &= 5.0 + t_{9,0.95} \cdot \frac{2.87}{\sqrt{10}} \quad (\alpha = 0.05) \\ &= 5.0 + 1.833 \cdot \frac{2.87}{\sqrt{10}} = 6.66 \end{aligned}$$

We know $\bar{x} = 6.68$. Thus $\bar{x} >$ U.L. This means H_0 is rejected and H_1: $\mu > \mu_0$ is accepted. Therefore we can conclude that the K.A.F. has not yet reduced the aircraft accident successfully within given period. If α increases, the value of the U.L. decreases and the probability of acceptance H_0 decreases more.

B. FAULT TREE ANALYSIS (FTA)

Fault tree analysis can be used to improve flight safety through the identification of safety critical items and make cost effective recommendations for their improvement. The identification of failures which impact the safety of a complex mechanical system of aircraft requires a disciplined formal methodology capable of addressing the causes of failure and failure interactions at low levels of complexity which influence the entire system. FTA can provide such a disciplined methodology and also be applied to quantitatively identify critical modes of failure (both hardware and human) whose occurrence could cause a hazard in flight. The application of FTA initially requires the definition of a system and once the system is defined the basic events are identified by starting with the accident and looking for its cause at a lower level of complexity. By repetition of this cause and effect relationship, the most elementary cause is finally deduced. The interconnections of the causal events with logic symbols form the branches of the fault tree. The quantitative evaluation of the probability of system failure requires the collection of failure rate data from which basic probabilities are determined. These basic event probabilities are combined using rules of Boolean algebra to determine criticality of each basic event. Based on relative criticalities, cost effectiveness techniques can be used to decrease probabilities of basic hazards.

A fault tree is a failure analysis technique which analyzes system failures beginning at the highest level of complexity and ending at the lowest level of complexity. The upper most event is identified as an accident which m· ·ave several degrees of severity. The degree of severity is not identified on the fault tree diagram but is accounted for in the cost effectiveness calculation. The tree construction is a logical process producing a graphical display of events such that all possible causes of a particular failure are shown below that failure. Subsystem failures are further subdivided and depicted in greater detail until the bottom of the tree is reached. The tree is structured to systematically show contributory events and failures and their relationship to each other and to the accident. Each component of the subsystem capable of producing an event is examined and how its failure would contribute to a mishap determined.

According to Hammer (1972), in the application of the fault tree methodology the following assumptions are generally made, concerning the characteristics of components, conditions, actions and events:

a. Components, subsystems and similar items can have only two conditional modes; they can either operate successfully or fail. No operation is partially successful.

b. Basic failures are independent of each other.

c. Each item has a constant failure rate that conforms to an exponential distribution.

The benefit of the generalized fault tree structure is realized through the general applicability of the improvement recommendations, derived from the fault tree analysis.

The author will draw a fault tree diagram based on the K.A.F. aircraft accident data. The primary factors of K.A.F. aircraft accidents in the 1970's were classified into six categories, i.e., pilot, maintenance, material, supervisory, environmental, and unknown factor. Fault tree must include detailed fault factors from top structure to subsystem, but K.A.F. data has not been collected in sufficient detail to evaluate the most effective use of FTA. For example, material factors of K.A.F. are shown in Table VI. What was the basic event of flight control in Table VI? Was it pitch, yaw, or roll failure? If the failure was due to yaw, what was the basic event of yaw? Was it caused by wear, shock, or vibration? The fuel system can be included as a subsystem of thrust control and also must be divided into subsystems. Data presented in Table VI is inadequate for applying FTA.

Among the primary factors of K.A.F. data pilot, maintenance, supervisory, and environmental factors are human error. Fault tree diagram of K.A.F. accident data is shown in Appendix B. More subsystems and basic events were added to illustrate a sample aircraft accident fault tree and develop the methodology for collecting and applying data. A method to collect data will be described below.

1. Data Collection

For FTA, the data is not confined only to major and minor accidents. Incident and Forced/Precautionary Landing data are also included, i.e., accidents are sorted into categories such as:

a. Major accident

b. Minor accident

Table VI

Material Factors by Year of Accident (Major & Minor)

Item \ Year	70	71	72	73	74	75	76	77	78	79	Total
Flight Control				1							1
Fuel System	1		1			1	1	1		2	7
Turbine Sect.				1							1
Compressor Section		1				1	2				4
Ignition System	1										1
Oil System				1							1
Elec. System		1									1
Landing Gear				2			1				3
Engine									1		1
Propeller Unit							1				1
Piston Rod		1									1
Flare Misfire				1							1
Flame Out				1							1
Fire		1				1	1				3
Total	2	4	1	7		3	6	1	1	2	27

c. Incident.

d. Forced/precautionary Landing.

Basic events which will be contributed to accidents in these subcategories are:

a. Supervisory factors.

b. Psychophysiological factors.

c. Environmental factors.

d. Material failure.

e. Maintenance.

Sample format of supervisory factors is shown in Table VII. More detailed data to be collected is presented in Section V.

2. <u>Development of an Equation for Corrective Action Recommendations</u>

This section concentrates on the development of an equation by which to evaluate cost effectiveness in terms of parameters derived from the fault tree analysis and parameters which may be readily estimated from the data.

The cost effectiveness index provides a measure of dollars saved per dollar spent in implementing recommendations. It is based on the projected percentage improvement in criticality if the improvement recommendation is implemented. The cost effectiveness index is the ratio of cost savings to improvement cost.

$$CE = \frac{C_S}{C_I} \qquad (1)$$

where:

Table VII

Example Supervisory Factor Reporting Format

SUPERVISORY FACTORS		Major	Minor	Incident	Forced/precaution Landing	Total
Inadequate weather analysis	Distraction	1				2
	Fatigue			1		
Inadequate Briefing	Overconfidence		2			3
	Fatigue			1		
Poor crew coordination	Preoccupied with personal problem			1		2
	Fatigue				1	
Flight beyond capacity	Limited experience	3				5
	Inadequate training		2			
Faulty flight plan	Overconfidence			1		3
	Preocc. w/pers. prob.			1		
	Fatigue		1			
Hurried departure	Panic			1		3
	Apprehension		1			
	Excessive Motivation to succeed			1		
Delayed departure	Apprehension			1		2
	Lack of self-confidence			1		
TOTAL		4	5	5	1	20

CE = cost effectiveness index

C_S = cost savings

C_I = improvement cost

The cost savings may be expressed in terms of the difference in total accident cost achieved by implementing the improvement recommendation. This may be expressed as:

$$C_S = N(C_A - C_{AI}) \quad (2)$$

where:

C_S = cost savings

N = number of accidents

C_A = cost of accident without improvement

C_{AI} = cost of accident with improvement

The general cost of a single accident may be expressed as:

$$C_A = (CR)(C_H) \sum_i \alpha_i \gamma_i \quad (3)$$

where:

CR = criticality

C_H = cost of a total lost

α_i = probability of an accident being of severity i

γ_i = relative cost of an accident of severity i

i = 1 - major incident

i = 2 - minor accident

i = 3 - incident

i = 4 - forced/precaution landing

This equation may be rationalized in terms of the criticality representing the probability of an accident of any severity occurring due to a given basic fault. The probability of the accident being of severity i is then $(CR)(\alpha_i)$. The cost of an accident of severity i is $(C_H)(\gamma_i)$. The cost likely to be incurred due to accidents of all severities is the sum of the products of these terms as expressed in the equation above.

The criticality after implementation of the improvement recommendation may be expressed as:

$$CR' = (1 - \beta)(CR) \tag{4}$$

where:

β = percent improvement in criticality

The cost of an accident after implementation of the improvement recommendation may then be expressed as:

$$C_{AI} = (1-\beta)(CR)(C_H) \sum_i \alpha_i \gamma_i \tag{5}$$

By substituting equations (3) and (5) into equation (2), an expression for cost savings is obtained in terms of parameters which have known numerical values.

$$C_S = N(C_A - C_{AI})$$

$$= N\{(CR)(C_H)\sum_i \alpha_i \gamma_i - (1-\beta)(CR)(C_H)\sum_i \alpha_i \gamma_i\}$$

$$= N(CR)(C_H)\{1 - (1-\beta)\}\sum_i \alpha_i \gamma_i$$

Thus

$$C_S = N\beta(CR)(C_H)\sum_i \alpha_i \gamma_i \tag{6}$$

An expression for the cost effectiveness ratio is obtained by substituting equation (6) into equation (1).

$$CE = \frac{C_S}{C_I} = \frac{N\beta(CR)(C_H)}{C_I}\sum_i \alpha_i \gamma_i$$

Thus

$$CE = N\beta(CR)\frac{C_H}{C_I}\sum_i \alpha_i \gamma_i \tag{7}$$

In order to apply this formula we have to set up a general criteria for each item.

a. Criticality (CR)

The author uses the definition of CR suggested by Birnbaum (1975). Let g be a function that computes the probability of the top event in terms of the basic event probabilities. To generate this function we need a Boolean expression for the top event in terms of the Boolean variables of the basic event. The outcome of each basic event at time t has an indicator variable $Y_i(t)$,

$$Y_i(t) = \begin{cases} 1 & \text{when basic event i has occurred at time t} \\ 0 & \text{otherwise} \end{cases}$$

If the state of each basic event is random, the probability that event i occurs by time t can be defined to be $F_i(t)$. If $\lambda_i(t)dt$ is defined to be the probability that event i occurs between t and t+dt, given that event i has not occurred by time t, then $F_i(t)$ can be expressed in terms of $\lambda_i(t)$:

$$F_i(t) = 1 - e^{-\int_0^t \lambda_i(t)dt}$$

$\lambda_i(t)$ is commonly referred to as the hazard or failure rate at time t.

If we construct a fault tree where the top event is system failure and the basic events are component failures, then Birnbaum's definition of component importance becomes

$$\frac{\partial g\{\underline{F}(t)\}}{F_i(t)} = g\{1_i,\underline{F}(t)\} - g\{0_i,\underline{F}(t)\}$$

where $g\{\underline{F}(t)\}$ is the probability that the top event occurs by time t. The above expression is the probability that the system is in a state in which the functioning of component i is critical: the system functions when i functions, the system fails when i fails. The probability that the system is in a state at time t in which component i is critical and that component i has failed by time t is the criticality of the ith basic event, i.e.,

$$CR = [g\{1_i,\underline{F}(t)\} - g\{0_i,\underline{F}(t)\}]F_i(t).$$

Example

Assume that the fighter aircraft accident data (including incident and forced/precaution landing) of the K.A.F. was collected for a 10 year period and a fault tree diagram was constructed the same as in Appendix B. From this diagram, the number of basic event accidents due to insufficient experience is 3. What is the basic event failure probability, head event probability and basic event criticality?

Before solving this problem, assume the following data was collected.

Total flight time of fighter aircraft	606,100 hr
Total sorties	586,600
Average flight time	1.033 hr

Assuming an exponential failure distribution, the failure rate is:

$$\lambda = \frac{3}{606,100} = 4.95 \times 10^{-6}/\text{hr}$$

Probability of basic event 'limited experience' is:

$$F_1(t) = 1 - e^{-\lambda t} \doteq \lambda t = 4.95 \times 10^{-6} \times 1.033$$

$$= 5.11 \times 10^{-6}$$

For basic event 'inadequate training',

$$\lambda = \frac{2}{606,100} = 3.30 \times 10^{-6}/\text{hr}$$

$$F_2(t) = \lambda t = 3.30 \times 10^{-6} \times 1.033$$

$$= 3.41 \quad 10^{-6}$$

Then, the probability of flight beyond capability P_{14} is:

$$P_{14} = 1 - \prod_{i=1}^{2} (1 - F_i)$$

$$= 1 - (1 - 5.1 \times 10^{-6})(1 - 3.41 \times 10^{-6})$$

$$= 8.52 \times 10^{-6}$$

In the same way,

P_{11} = Probability of faulty flight plan

$= 5.10 \times 10^{-6}$

P_{12} = Probability of inadequate W_X analysis

$= 3.40 \times 10^{-6}$

P_{13} = Probability of poor crew coordination

$= 5.10 \times 10^{-6}$

$$P_{15} = \text{Probability of inadequate briefing}$$

$$= 5.11 \times 10^{-6}$$

$$P_{21} = \text{Probability of supervisory error}$$

$$= 1 - \prod_{i=1}^{5} (1 - P_{1i})$$

$$= 1 - (1 - 5.10 \times 10^{-6})(1 - 3.40 \times 10^{-6})(1 - 5.10 \times 10^{-6})$$

$$\cdot (1 - 8.52 \times 10^{-6})(1 - 5.11 \times 10^{-6})$$

$$= 2.72 \times 10^{-5}$$

If we collected all of the other event data and the probabilities of each event calculated as in Table VIII, then, by using the procedure with AND or OR gate, we have:

Table VIII

Failure Probability

EVENTS	Failure Probability
Maintenance	10.10×10^{-5}
Environmental Condition	1.03×10^{-5}
Psychophysiological Disturbance	2.05×10^{-5}
Flight Control	9.25×10^{-5}
Thrust Control	8.55×10^{-5}
Landing Gear	6.18×10^{-5}
Unknown Crash	1.20×10^{-5}

Probability of pilot error $= 5.80 \times 10^{-5}$

Probability of human error $= 6.81 \times 10^{-5}$

Probability of material failure $= 2.40 \times 10^{-4}$

Probability of head event failure $= 3.20 \times 10^{-4}$

Calculation of criticality:

If the ith component 'Insufficient Experience' failed,

$$g\{1_i, \underline{F}(t)\} = 3.20 \times 10^{-4}.$$

If the ith component 'Insufficient Experience' didn't fail and the head event failure occurred, then

$$F_1(t) = \lambda t = 0 \times 1.033 = 0$$

Thus

$$P_{15} = 1 - \prod_{i=1}^{2} (1 - F_i) = 1 - (1-0)(1 - 3.41 \times 10^{-6})$$

$$= 3.41 \times 10^{-6}$$

$$P_{21} = 1 - (1 - 5.10 \times 10^{-6})(1 - 3.40 \times 10^{-6})(1 - 5.11 \times 10^{-6})$$

$$\cdot (1 - 5.10 \times 10^{-6})(1 - 3.41 \times 10^{-6})$$

$$= 2.21 \times 10^{-5}$$

Finally we get the probability of head event failure as 3.15×10^{-4}. Thus,

$$CR = (3.20 \times 10^{-4} - 3.15 \times 10^{-4})(5.11 \times 10^{-6})$$
$$= 2.56 \times 10^{-11}$$

b. Number of Accidents (N)

An estimate of the number of accidents in the remaining service life of fighter aircraft in the K.A.F. would be calculated if we knew the average sorties flown per year and the projected remaining life of operation. Suppose the average sorties flown per year was 58660 and the average operational life of fighter type aircraft was 8 years.

From the fault tree it was determined that the probability of an accident of any type of basic event is 3.20×10^{-4}. Then the number of accidents expected to occur in the remaining operational life is:

$$N = (58660)(8)(3.20 \times 10^{-4}) = 150$$

Though the above value was derived by estimate, its absolute value is unimportant since ranking of cost effective procedures id based on a relative figure of merit.

c. Percent Improvement in Criticality (β)

The percent improvement achievable by implementing suggested improvement recommendations for the particular fault is based on an engineering judgment.

d. Ratio of Total Loss to Improvement Cost $(\frac{C_H}{C_I})$

Total loss is equivalent to the average acquisition cost of all types of fighter aircraft. For each improvement technique, estimates can be made of the cost to implement the improvement as a fraction of the acquisition cost, C_I/C_H.

e. Relative Cost of an Accident of Severity i (γ_i)

The relative cost associated with a given accident depends on its severity. Accident costs will be normalized with respect to the average of the manhours required to complete repair or replacement of major damage for all kinds of fighter aircraft.

Suppose we know the following data.

1. Major Damage Classification

Type of aircraft	F-K	F-M	F-X	F-Y	F-Z
Manhours	500	600	700	800	900

2. Minor Damage Classification

Type of aircraft	F-K	F-M	F-X	F-Y	F-Z
Manhours	200	180	150	120	50

Then the average of the manhours required to complete repair or replacement of major damage for all types of aircraft is:

$$(500 + 600 + 700 + 800 + 911)/5 = 700$$

The average manhours of minor damage is 140. The relative cost of a minor accident is then 140/700 = .2. The same ratio can be applied in relating an incident to a minor accident and a forced/precaution landing to an incident. Assume the relative cost of incident is 0.03 and forced/precaution landing is 0.004 for calculation of COST effectiveness as an example.

f. Probability of an Accident Being of Severity i (α_i)

It is often the case that basic events have different probabilities of inducing accidents of varying severity, i.e., some event will always result in a major accident, whereas other events may induce a major accident, minor accident, incident, or forced landing. The probabilities depend on other interacting elements in the system. Therefore, in arriving at a cost effectiveness index, the criticality of a basic fault must be weighed to reflect its impact on accident severity. This is achieved by introducing a factor α_i into the expression for cost savings to account for the probability of a given accident severity. The evaluation of this parameter requires an engineering judgment to be made of the probabilities of a basic fault causing accidents of varying severities.

Sample calculation of CE

Assume that the accident occurred from limited experience (Basic event 1.8 of Appendix B). The cause of failure was due to "order to pilot beyond capability on flight". The corrective action recommended is an establishment of experience criteria. The cost effectiveness of this recommendation is:

From collected data and engineering judgment, assume we have β = 70%, α_1 = 10%, α_2 = 40%, α_3 = 40%, α_4 = 10% and C_I/C_H = 0.1. Then

$$
\begin{aligned}
CE &= N\ (CR)\left(\frac{C_H}{C_I}\right) \sum_{i=1}^{4} \alpha_i \gamma_i \\
&= 150 \times 0.7 \times (2.56 \times 10^{-11}) \times \frac{1}{0.1} \times (0.1 \times 1.0 \\
&\quad + 0.4 \times 0.2 + 0.4 \times 0.03 + 0.1 \times 0.0004) \\
&= 5.17 \times 10^{-9}
\end{aligned}
$$

The relative cost effectiveness is obtained by proportion of the above value to the most cost effective item in the list, i.e., set the most cost effective item to be 1.0. For example, suppose supervisory error in maintenance has the greatest CE value of 65, then relative cost effectiveness of 3.5 in Appendix B is 1 and accident due to limited experience is $5.17 \times 10^{-7}/65 = 7.9 \times 10^{-11}$. Example cost effectiveness ranking is shown in Table IX. We can decide the basic event fault is not critical and then it will be eliminated from Table IX (e.g., if $CR < 10^{-15}$).

FTA was suggested as a method of system safety analysis which can improve flight safety through identification of safety critical items and make cost effective recommendations. FTA is a detailed deductive analysis that usually requires considerable system information. It can be a valuable design tool. FTA can also be a diagnostic tool in that it can predict the most likely causes of system failure in the event of system breakdown.

Table IX

Sample Cost Effectiveness Ranking

ID	Description	Cause of Failure	Improvement Recommendation	Relative Cost-Effectiveness
3.5	Supervisor	Inadequate Inspection	Improved Training	1
6.5	General Mechanic	Inadequate Inspection	Improved Training	6.8×10^{-3}
6.2	Valves	Loss of Hydraulic Pressure	Increase Preventive Maintenance	5.3×10^{-3}
7.6	Damaged Blade	Loss of Main Rotor Thrust	Improved Pilot Training	5.9×10^{-4}
6.5	Mechanical Failure	Loss of Hydraulic Control	Redesign Pressure Switch for Increased Reliability	3.2×10^{-4}
6.3	Fretted Fitting	Loss of Hydraulic Pressure	Improve Maintenance Training	8.8×10^{-5}
6.6	Electrical Failure	No Fuel Engine	Redesign Solenoid Coil for Higher Reliability	1.2×10^{-5}
4.1	Wind Gust	Weather Conditions Cause Pilot Error	Improve Pilot Training	4.5×10^{-6}

C. CRITICAL INCIDENT TECHNIQUE (CIT)

The CIT consists of a set of procedures for collecting direct observations of human behavior in such a way as to facilitate their potential usefulness in solving practical problems. As a measure for accident research, it reveals causal factors in terms of human errors and unsafe conditions that lead to aircraft accidents and it provides more information about accident causes and a more sensitive measure of total accident performance than other available methods of accident study.

The CIT has been used to collect both accident and near accident data without any discrimination being made between the two types of data. However, in particular cases the investigator may confine his attention to one or the other type of data.

By collection and categorization of common errors from human factors data in aircraft operation, possible direction of accident prevention and recommendation will be provided. For example, if we collect data of specific experiences from pilots in taking-off, flying an instrument, landings, using controls and using instruments, then the data may provide many factual incidents that can be used as a basis for planning research on the design of instruments, controls, training, and the arrangement of these within the cockpit.

To be useful the incidents must be detailed enough a) to allow the investigator to make inferences and predictions about the behavior of the person involved and b) to leave little doubt about the consequences of the behavior and the effects of the incident.

The two primary steps included in the critical incident procedure are:

1. <u>Collection of the Data</u>

The most important item for accident research is the real data in detail. The CIT is frequently used to collect data on observations previously made. This is usually satisfactory when the incidents reported are fairly recent and the observers were motivated to make detailed observations and evaluations at the time the incident occurred.

The practical problem in collecting the data for describing an activity refers to the problem of how it should be obtained from the observers. This applies especially to the problem of collecting recalled data in the form of critical incidents. Three procedures for collecting data are described below.

a. Interviews

The use of trained personnel to explain to observers precisely what data are desired and to record the incidents, making sure that all necessary details are supplied, is probably the most satisfactory data collection procedure. This type of interview is somewhat different from the other types of interview and a brief summary of the principle mishap factors involved will be given.

b. Questionnaires

If the group becomes large, a questionnaire procedure is convenient.

c. Record Forms

One other procedure for collecting data is by means of written records. There are two varieties of recording: one is to record details of incidents as they happen. This situation is very similar to that described in connection with obtaining incidents by interviews above.

A variation of this procedure is to record such incidents on forms which describe most of the possible types of incidents by placing a check or tally in the appropriate place.

As additional *information becomes* available on the nature of the components which make up activities, observers may thus collect data more efficiently by using forms for recording and classifying observations.

2. <u>Analyzing the Data</u>

The collected data of a large sample of incidents provides a functional description of the activity in terms of specific behaviors. The purpose of the data analysis stage is to summarize and describe the data in an efficient manner so that it can be used effectively.

For analyzing the data we have to consider two primary problems involved. These problems will be discussed below.

a. Frame of Reference

There are countless ways in which a given set of incidents can be classified. In selecting the general nature of the classification, the principle consideration should usually be that of the uses to be made of the data. The preferred categories will be those believed to be most valuable in using the statement of requirements. Other considerations are ease and accuracy of classifying the data.

b. Category Formulation

The induction of categories from the basic data in the form of incidents is a task requiring insight, experience, and judgment. The usual procedure is to sort a relatively small sample of incidents into piles that are related to the frame of reference selected. After these tentative categories have been established, brief definitions of them are made, and additional incidents are classified into them. During this process, needs for redefinition and for the development of new categories are noted. The tentative categories are modified as indicated and the process continued until the incidents have been classified. The larger categories are subdivided into smaller groups and the incidents that describe very nearly the same type of behavior are placed together. The definition for all the categories and major headings should then be re-examined in terms of the actual incidents classified under each.

A major problem area in CIT involves actual data collection. The following items will be applicable to interview

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or record form in order to collect human factors data in aircraft operation.

1. Description of the occurrence
    a. Aircraft
        (1) Model
        (2) Configuration when anomaly occurred (gear, flaps, thrust, fuel, quantity, etc.)
    b. Type of operation
    c. Time and location
        (1) Local time
        (2) Elapsed time since departure from parking area
        (3) Phase of flight
        (4) Geographic location
    d. Nature of the anomaly (describe the deviation from normal or expected performance as precisely as possible)
    e. Radio navigation facilities in use and type of navigation
    f. Detection of the anomaly (Identify the person responsible for each pertinent decision, command, action, communication or interaction with others)
        (1) Who first noticed the deviation? (Aircraft commander, air traffic controller, maintenance personnel, or others (explain)). Who should have?
        (2) What brought it to his attention? What should have?
    g. Cockpit environment preceding the anomaly.
        (1) Was there anything unusual about the operation?
        (2) Were there any distractions immediately before the anomaly occurred?
        (3) What was the weather at the time of the occurrence?
    h. What actions immediately preceded the anomaly, in order of occurrence?
        (1) Did any of these actions contribute to the anomaly?
        (2) What decisions motivated this action? Who made them?

(3) What information was the basis for the decisions? Was the information correct?

i. Was there any indication before the anomaly that it was going to occur or might occur? If so:

(1) What was the indication?

(2) Who noticed it?

(3) Was it noticed immediately? If not, why not?

2. Recovery following the occurrence

a. What happened after the anomaly occurred?

(1) What decisions were made?

(2) By whom?

(3) For what reasons?

b. What actions were taken to correct the deviation?

(1) By whom was each action initiated? When? Why?

c. What effect did each action have?

(1) Did it help recovery?

(2) Did it hinder recovery?

d. Did any complicating factors arise during the recovery period? (After the initial deviation, other events can occur while the crew is recovering from the first one. Be careful to identify these.)

e. Was normal operation restored? How long did it take?

f. Was safety threatened at any time?

(1) If so, what was the nature of the threat?

(2) Was it recognized at the time?

(3) Who recognized it?

(4) How was it recognized?

(5) How long did it last?

(6) What was done to control or minimize the threat?

(7) Could the threat have been controlled more effectively?

3. Background

a. If pertinent, describe the history of the personnel involved and of the airplane and facilities utilized in this flight.

(1) Nutrition and rest: Describe meals as to time eaten and type of food and sleeping time.

(2) Were there any medical or physiological problems?

(3) Describe the crew's rest and duty schedule for this flight sequence. Was this flight their scheduled activity?

a) Do the pilots believe the duty or rest schedule was a factor?

b) Describe their activities during the preceding day.

(4) Were there any problems within the flight crew with respect to discipline, coordination, ability, personality factors?

(5) Were there any other problems (ground support personnel, controller, management, others)?

(6) Were any other factors pertinent during the period prior to flight?

b. Describe in brief the history of this flight prior to the occurrence. Emphasize any decisions, actions, events or omissions which might have been related to the later anomaly.

(1) Was servicing and ground support normal?

(2) Were there any supervisory problems?

(3) Were there any ground or flight delays?

(4) Were there any problems at the departure airport?

(5) Were there any air traffic control or airways facilities problems?

(6) Was weather a problem at any time? If so, how?

4. Analysis and recommendations

This section should contain only the opinions and recommendations of the person reporting the occurrence.

a. Was the situation evaluated correctly when the anomaly was detected?

(1) If so, were any special factors responsible?

(2) If not, why was the evaluation incorrect?

(3) Could anything have improved the accuracy of the evaluation?

b. Was the detection of the anomaly as prompt as it should have been?

(1) If so, were any special factors responsible?

(2) If not, why was there a delay in detection?

(3) Could anything have improved the speed of detection?

c. Was the recovery from the deviation the most effective?

d. Was there any problem in flight crew management or coordination? Describe any deficiencies, problems or comments in detail.

e. Was the entire flight managed professionally and effectively?

(1) If not, what might have been done better?

f. Was Air Traffic Control involved in any way?

(1) If so, was the problem due to ATC handling or instructions?

(2) If so, was there any flight crew misunderstanding of ATC handling or instructions?

(3) Did ATC do anything to minimize the problem?

g. Was any airplane system involved?

(1) Did maintenance contribute to the problem?

h. Was this a fairly common problem?

i. Was pilot training adequate:

(1) To have prevented this occurrence?

(2) To correct or control it under these circumstances?

(3) To cope with it under all circumstances?

j. Were any of the following involved in any way? If so, how?

(1) Flight crew supervision?

(2) Flight dispatch?

(3) Flight or ground support?

(4) Other?

5. Supplement (for interviewer only)

a. Was the reporting person's memory entirely clear as to the details of this occurrence? If not, in what areas did he have difficulty remembering details?

b. In your opinion, did this incident pose a threat to flight safety? If so, how and why?

c. Add any additional comments or opinions you may have as to the factors involved in this occurrence and as to measures which might prevent such problems in the future.

After collecting the data by the methods given above, we can analyze the data. The sample size must be as large as possible for categorization. Table X is the classification of pilot-error experiences as a result of analyzing the data. This is just an example to show how to analyze the data.

In summary, the CIT is used as a method of discovering and attempting to reduce or control hazardous situations before accidents occur.

In effect, the CIT accomplishes the same end result as an accident investigation: identification through personal involvement of a hazard that has or could result in injury or damage. The CIT has been used in evaluation of pilot safety and has proven beneficial as a qualitative safety technique.

D. OTHER STATISTICAL METHODS

In general, accidents are not single causation events, rather multivariate factors. So we can use many kinds of statistical methods to analyze the data. Multiple regression analysis and cluster analysis are widely used. Different statistical methods can be applied to the collected data.

The following is an example of the use of statistical methods. Suppose it is important to determine if there is a statistically significant difference between the pilot factor accident rates of experienced and inexperienced pilots

Table X

Example Classification of Pilot Error Experiences

	Type of Error	Number of Errors
1	Errors in interpreting multi-revolution instruments a. Errors involving an instrument which has more than one pointer (e.g., misreading the altimeter) b. Errors involving an instrument which has a pointer and a rotating dial viewed through a window (e.g., misreading the tachometer, air-speed indicator)	
2	Substitution errors a. Mistaking one instrument for another b. Confusing which engine is referred to by an instrument c. Difficulty in locating an instrument because of unfamiliar arrangement of instruments	
3	Reversal errors (e.g., reversals in interpreting the direction of bank shown in attitude indicator, reversals in interpreting direction from compasses)	
4	Errors due to illusions: Faulty interpretation of the position of an aircraft because body sensations do not agree with what the instruments show	
5	Using an instrument that is inoperative	
6	Signal interpretation errors: Failure to notice a warning light in the aircraft, or confusing one warning light with another	

(in this case, the "experience" and "inexperience" would have to be defined). Choose some time frame and let

h_1 = number of flight hours flown by experienced pilots

h_2 = number of flight hours flown by inexperienced pilots

a_1 = number of pilot factor accidents involving experienced pilots

a_2 = number of pilot factor accidents involving inexperienced pilots.

Then the rates for experienced and inexperienced pilots are $(a_1 \times 100{,}000)/h_1$ and $(a_2 \times 100{,}000)/h_2$, respectively. We want to test the null hypothesis:

H_0: There is no difference in accident potential between experienced and inexperienced pilots

H_1: Not H_0

Testing H_0 amounts to testing a hypothesis about the success probability in a binomial distribution. Let a and h be the number of accidents and time, respectively, for the group with the larger accident rate (e.g., $a = a_1$ and $h = h_1$, if the experienced pilots had the higher rate).

Let

$$\hat{p} = \frac{a}{a_1 + a_2}, \qquad p = \frac{h}{h_1 + h_2}, \qquad n = a_1 + a_2.$$

We will reject H_0 if $\hat{p}$ and p differ too much. Compute $T = P(X \geq a)$, where X has a binomial distribution with parameters n and p. Thus,

$$T = \sum_{i=a}^{n} \frac{n!}{i!(n-i)!} p^i (1-p)^{n-i}$$

Let α be the significance level of the test (e.g., $\alpha = 0.05$). If $T > \alpha/2$, then accept H_0. That is, we would conclude that there is not sufficient evidence based on this data, to say there is a difference between experienced and inexperienced pilots. If $T \leq \alpha/2$, then reject H_0 and conclude (at significance level α) that there is a difference between experienced and inexperienced pilots.

The above test is an example of a two-sided test. It is designed to answer the question, "Is there a difference between experienced and inexperienced pilots?" A one-sided test could be done to answer the question, "Are experienced pilots safer?" The null hypothesis in this case would be:

H_0: experienced pilots are not safer than inexperienced pilots

For this case, let $a = a_1$ and $h = h_1$, and compute T, $\hat{p}$, p, and n according to the same formulas as before. We will reject H_0 if $\hat{p}$ is much larger than p. If $T > \alpha$, we accept H_0. That is, we conclude that there is not sufficient evidence, based on this data, to say that experienced pilots are safer (with significance level α). If $T \leq \alpha$, then reject H_0 and conclude (at significance level α) that experienced pilots are safer.

V. CONCLUSIONS/RECOMMENDATIONS

Aircraft accidents are rarely caused by a single factor. Generally, accidents are the end result of system deficiencies, human error and design deficiencies coming together simultaneously. The most commonly designated cause of accidents is human error. For flight safety, a systematic accident prevention program should include consideration of all possible sources. Accident prevention is best pursued within the framework of this program. There are certain fundamental concepts and methods which, if properly applied, can increase the probability of success in the determination of factors contributing to an accident. Several methodologies for the measurement of flight safety and data collection have been proposed in this thesis for inclusion in the K.A.F. safety program.

The primary goal of accident prevention progam is to prevent mishaps. Therefore, the K.A.F. needs to develop a safety program based on the following data collection and analysis methods:

1. Develop a format which will describe each element (e.g., pilot, maintenance, supervisory error, material failure) in detail. For example the U.S.A.F. has developed a system for accident data collection (see Appendix C) which provides for a comprehensive consideration of variables involved in flight safety. The following elements are contained in the U.S.A.F. data collection system:

    a. Ground mishap report.

    b. Aircraft flight mishap report.

c. Aircraft maintenance and material report.

d. Life sciences report of an individual.

e. Psychophysiological and environmental factors.

f. Personal data.

2. K.A.F. needs to consider the application of the critical incident technique (CIT) as described in Section IV to collect and analyze data. CIT is used in evaluation of flight safety and as a qualitative safety technique.

3. Use the format of system safety hazard analysis (SSHA) for fault tree analysis. In system safety analysis, the results of SSHA should be used to determine what safety requirements are needed to minimize and control hazards to an acceptable level. The SSHA should be accomplished by a systematic evaluation of each subsystem /component to determine how much each element/subsystem could potentially contribute to a specific hazard. A sample format of SSHA reporting is shown in Appendix D.

4. Finally, the following fundamental data should be filed in the computer for use in a safety analysis and program evaluation.

<u>Group data</u>

(1) Total number of pilots engaged in flying by month and year.

(2) Flight time of Command, Wing, and Squadron in month and year by model.

(3) Total number of accidents in month and year by Command, Wing, and Squadron.

<u>Pilot</u>

a. Biographical data

(1) Name

(2) Rank

(3) Date of birth

(4) Date of graduation from undergraduate flight training

(5) Wing and Squadron assigned

(6) Total flight time

(7) Total jet time, conventional aircraft time, helicopter time

(8) Total instructor time

(9) Total weather/instrument time

(10) Number and type of accidents the individual has had.

b. Accident data

(1) Name of personnel involved

(2) Date of occurrence

(3) Type of mission

(4) Phase of mission

(5) Duration of flight

(6) Type of accident

(7) Prime and contributing factor

(8) Days since last flight

(9) Hours flown in last 24 and 48 hours

(10) Sorties flown in last 24 and 48 hours

(11) Hours flown in last 7, 30, 60, and 90 days

(12) Total time in this aircraft type

In addition, similar data should be collected on maintainers, supervisors, air traffic controllers, etc.

Aircraft

(1) Model

(2) Total flight time

(3) Date of last major inspection

(4) Flight time since last major inspection

Accident research is a systematic, empirical, and critical investigation of associated factors and their relationships in an accident. For this research, reliable and valid accident data are necessary. If the data are collected in detail and correctly by the formats and techniques proposed, it will provide a convenient method for a researcher to use in the development and application of a safety program. For example, the analysis of the variables or causal factors of aircraft accident such as human error, material failure or malfunction, and adverse influences of the environment on man and machine will allow the researcher to develop an analytical model for a specific mishap. There are several multivariate statistical techniques (e.g., factor and component analysis, cluster analysis, regression analysis, etc.) to analyze the accident data. These techniques can be used to determine significant interrelationships and to correct system inadequacies (i.e., what caused or allowed the accident to happen). Also, remedial actions (i.e., what can be done to preclude the occurrence of an accident) will be proposed.

Finally, application of the findings and recommendations are needed. Qualified investigators, researchers, and safety officers are necessary at each level of organization (Figure 21) and a feedback system should exist between and within each level. If a mishap occurs (here mishap includes major, minor accident, incident, and near miss), it has to be investigated and reported by a reporting system to Air Force Headquarters Safety Section through the Command. In the H.Q. Safety Section the data must be encoded, analyzed, and recommendations made known by the dissemination of mishap results and findings should be passed to Wing and Squadron through the Command. The Squadron must then take action on this recommendation. The recommendations including general trends of mishap components must be passed monthly to Wing and Squadron.

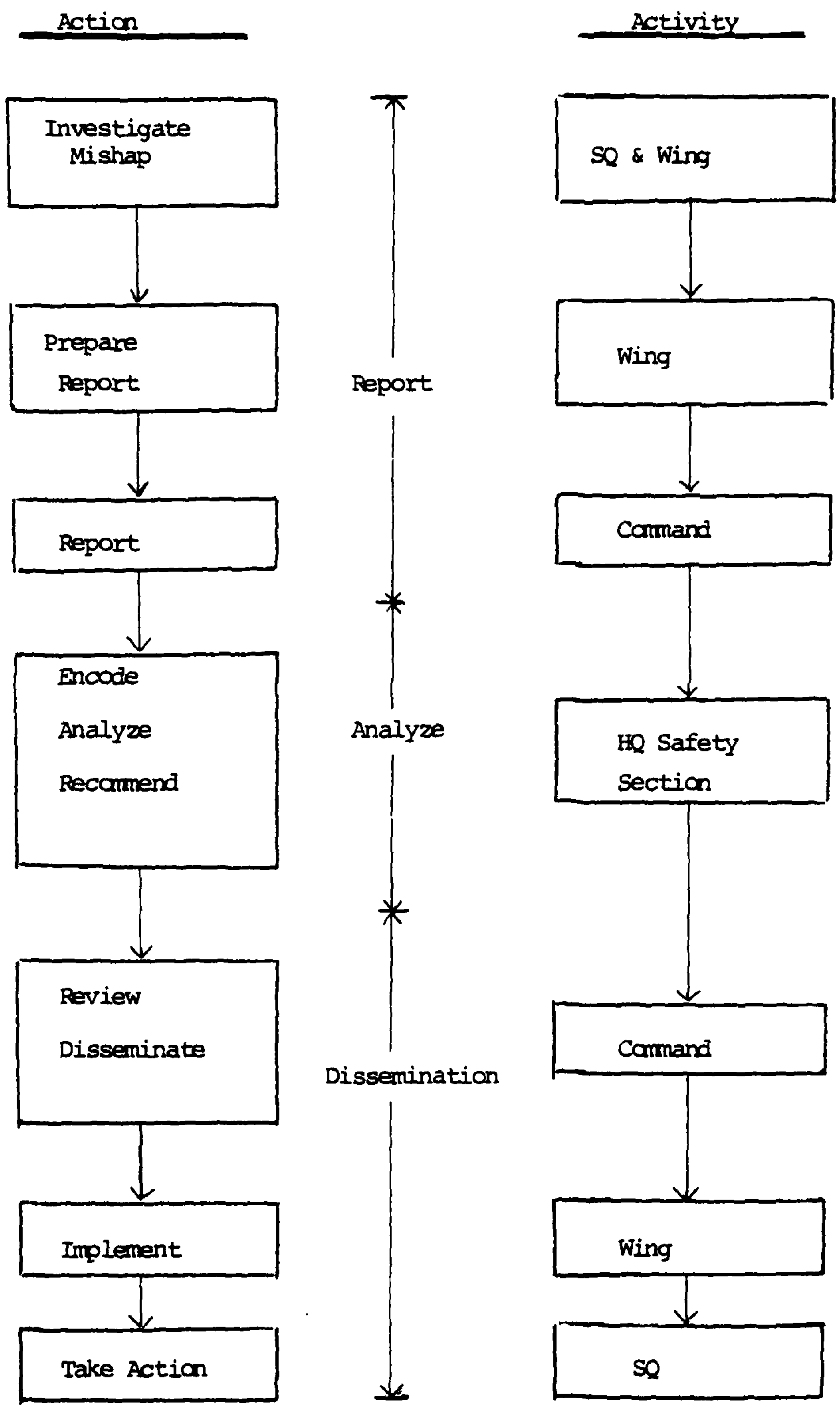


Figure 21. Proposed Information Flow for R.O.K. Safety Program

Appendix E is a sample trend chart developed by the U.S.A.F. and applicable to the K.A.F.

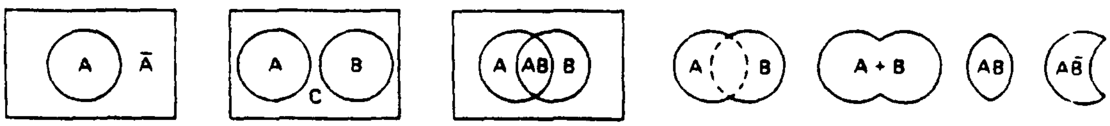
The safety program described in this thesis possesses the potential for reducing overall operational costs and maximizing aircraft availability. The end result of such a program can only serve to increase operational readiness and thereby maximize overall efficiency and military capability of the K.A.F.

APPENDIX A

BOOLEAN LOGIC AND ITS APPLICATIONS

Boolean algebra was developed originally for the study of symbolic logic. Its rules and expressions in mathematical symbols permit complicated propositions to be clarified and simplified. Boolean algebra is especially useful where conditions can be expressed in no more than two values, such as yes or no, true or false, on or off, up or down, go or no go. It has found wide application in areas other than symbolic logic. For example, it is used extensively in the design of computers and other electromechanical assemblies incorporating large numbers of on-off (switching) circuits. Other uses are in probability analysis, studies involving decision making, and more recently, in safety and fluidics. The chief difference between the various disciplines in their employment of Boolean algebra is in notation and symbology. Since the information in this section presents basic elements only, expressions most commonly found in safety analyses will be used.

A set is a group of objects having at least one characteristic in common. The set may be a collection of objects, conditions, events, symbols, ideas, or mathematical relationships. The unity of a set can be expressed by the number 1, and an empty set, which contains none of these, by 0. The numerals 1 and 0 are not quantitative values: 1 + 1 does not equal 2. They are merely symbols. There are no values between the two as there are in probability calculations. Set relationships are sometimes illustrated by Venn diagrams. The following rectangle represents a set of elements that have an undefined common characteristic. In addition, a subset has the characteristic A. All other elements in the set do not have the A characteristic and are considered being "not A," designated by $\bar{A}$. $\bar{A}$ is the complement of A, and vice versa. It can be seen that the total of A and $\bar{A}$ is the complete set, expressed mathematically by $A + \bar{A} = 1$, where the left side of the equation is the union of A and $\bar{A}$. The + sign is read "OR", and may be designated in mathematical expressions by other symbols, such as U.



The second diagram illustrates the concept of disjoint, or mutually exclusive, sets. The elements of one subset are not included in the others, and therefore are not interrelated (other than being in the same set). In this case, however, because A, B and C contain all the elements in the overall set, they are said to be mutually exclusive and exhaustive: $A + B + C = 1$

The third diagram indicates that some elements of A also have B characteristics. These are indicated by AB, A · B or A ∩ B, called the intersection of A and B. The intersection contains all the elements with the characteristics of both A and B. When all elements with the characteristic A are counted, those in AB will also be counted. The remaining diagrams in the row illustrate some of the relationships between union, intersection, and complement. Numerous other relationships that can be employed in mathematical expressions have been developed, some of them having been designed as laws. These are listed below, with some explanations on their meaning in Boolean logic.

RELATIONSHIP	LAW	EXPLANATION
$A \cdot 1 = A$	Full and Empty Sets	The only portion within 1 that is both 1 and A is that within A itself
$A \cdot 0 = 0$		An impossible condition; if it is within the set, it cannot be outside the set
$A + 0 = A$		The element in a subset plus anything outside the set will have only the characteristics of the subset
$A + 1 = 1$		The whole, expressed by 1, cannot be exceeded
$\bar{\bar{A}} = A$	Involution Law	The complement of the complement is the item itself
$A \cdot \bar{A} = 0$	Complementary Relations	An impossibility; a condition cannot be both A and $\bar{A}$ at the same time.
$A + \bar{A} = 1$		Those elements with a specific characteristic and those without it constitute the total set
$A \cdot A = A$	Idempotent Laws	An identity
$A + A = A$		Also an identity
$A \cdot B = B \cdot A$	Commutative Laws	The elements having both characteristics have them no matter the order in which expressed

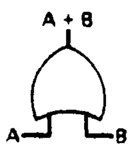
RELATIONSHIP	LAW	EXPLANATION
$A + B = B + A$		The total of those elements having the characteristic A or B will be the same no matter the order in which they are expressed
$A(B \cdot C) = (A \cdot B)C$	Associative Laws	The elements having all the characteristics A, B and C will have them no matter the order in which expressed
$A + (B + C) = (A + B) + C$		The total of all the elements in any subsets will be the same no matter the order in which expressed
$A(B + C) = (A \cdot B) + (A \cdot C)$	Distributive Laws	The union of one subset with two others can also be expressed as the union of their intersections
$A + (B \cdot C) = (A + B) \cdot (A + C)$		The union of one subset with the intersection of two others can also be expressed by the intersection of the unions of the common subset with the other two.
$A(A + B) = A$	Absorption Laws	$A(A + B) = AA + AB = A + AB$ since $AA = A$. $A + AB = A(1 + B) = A$ since B is included in 1
$A + (A \cdot B) = A$		$A + (A \cdot B) = A + AB = A(1 + B) = A$.
$\overline{A \cdot B} = \bar{A} + \bar{B}$	Dualization (de Morgan's) Laws	The complement of an intersection is the union of the individual complements.
$\overline{A + B} = \bar{A} \cdot \bar{B}$		The complement of the union is the intersection of the complements.

Other useful identities are frequently used for simplification of complex Boolean equations. Four of these are:

<u>Identity</u>	<u>Derivation</u>
$A + \bar{A}B = A + B$	Using the Distributive Law: $(A + \bar{A}) \cdot (A + B) = A + B$
$A \cdot (\bar{A} + B) = AB$	Using the Distributive Law: $A \cdot \bar{A} + AB = AB$
$(A + B)(\bar{A} + C) \cdot (A + C) = AC + BC$	Expanding the last two terms: $(A + B)(A\bar{A} + AC + \bar{A}C + CC)$. $CC = C$, $A\bar{A} = 0$, $AC + \bar{A}C = C(A + \bar{A}) = C(1) = C$, and $C + C = C$. $\therefore$ remainder is $(A + B)C$, or $AC + BC$.
$AB + \bar{A}C + BC = AB + \bar{A}C$	This can be simplified by adding a term such as $A + \bar{A}$. The left hand side then becomes: $AB + \bar{A}C + BC(A + \bar{A}) = AB(1 + C) + \bar{A}C(1 + B) = AB + \bar{A}C$.

GATE (CONNECTIVE)	SYMBOL	EXPLANATION	TRUTH TABLE

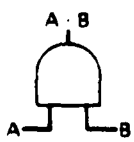
OR



The OR connective indicates that when one or more of the inputs or governing conditions is present, the statement will be true or an output will result. Conversely, the statement will be false if, and only if, none of the governing conditions is present.

A	B	OR	
0	0	0	(False)
0	1	1	(True)
1	0	1	(True)
1	1	1	(True)

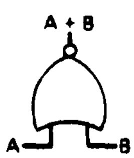
AND



The AND connective indicates that all of the governing conditions or inputs must be present for a statement to be true. If one of the conditions or inputs is missing, the statement is false.

A	B	AND	
0	0	0	(False)
0	1	0	(False)
1	0	0	(False)
1	1	1	(True)

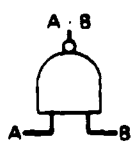
NOR



The NOR connective may be considered a "not OR" state. It indicates that when one or more of the inputs is present, the statement will be false or no output will result. When none of the inputs, neither A nor B, is present, an output will result.

A	B	NOR	
0	0	1	(True)
0	1	0	(False)
1	0	0	(False)
1	1	0	(False)

NAND

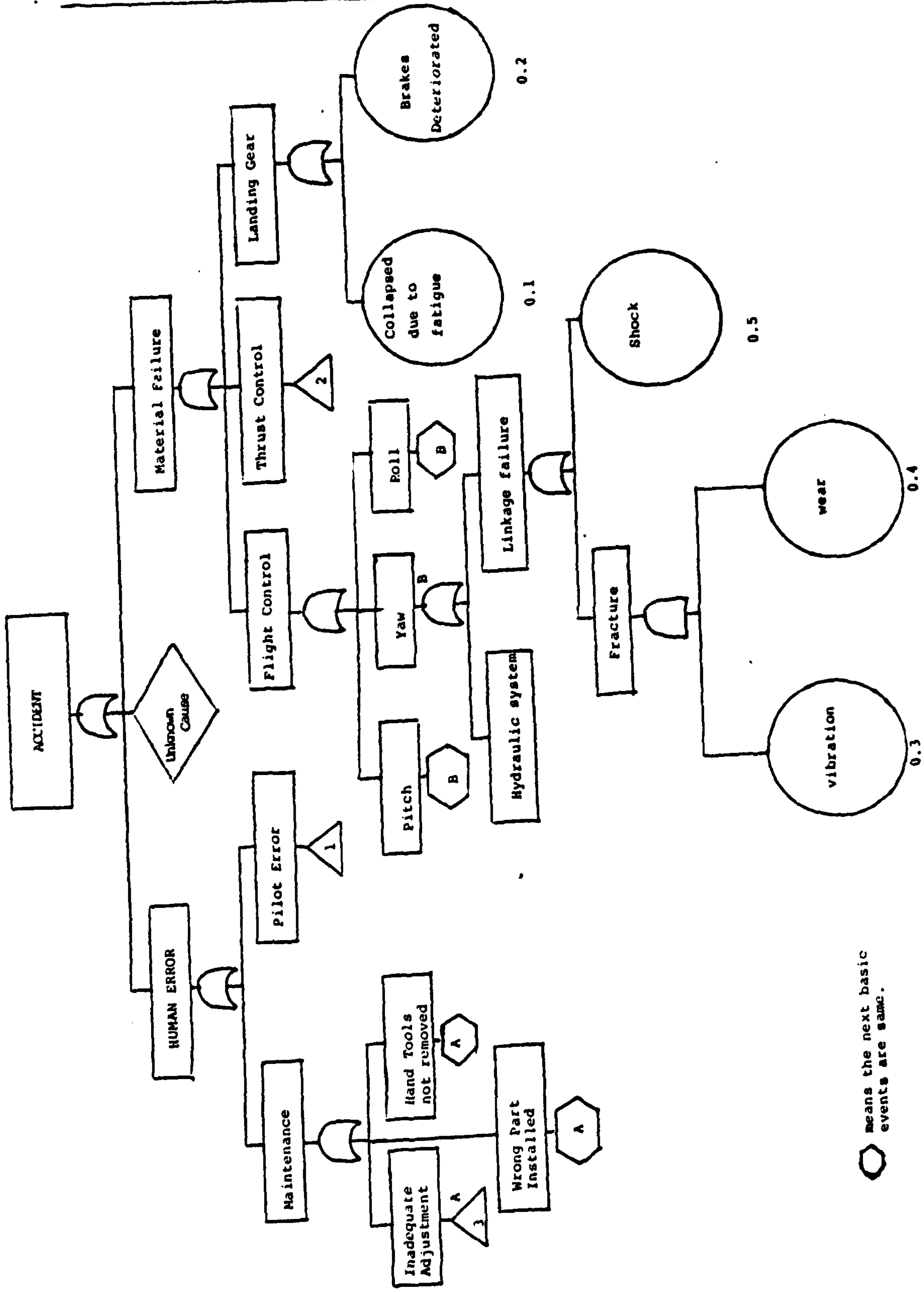


The NAND connective indicates that when all of the inputs or governing conditions or inputs are not present, the statement will be true or there will be an output. When all of the inputs or governing conditions are present, the statement will be false or there will be no output.

A	B	NAND	
0	0	1	(True)
0	1	1	(True)
1	0	1	(True)
1	1	0	(False)

APPENDIX B

FAULT TREE DIAGRAM FOR CRITICALITY ANALYSIS



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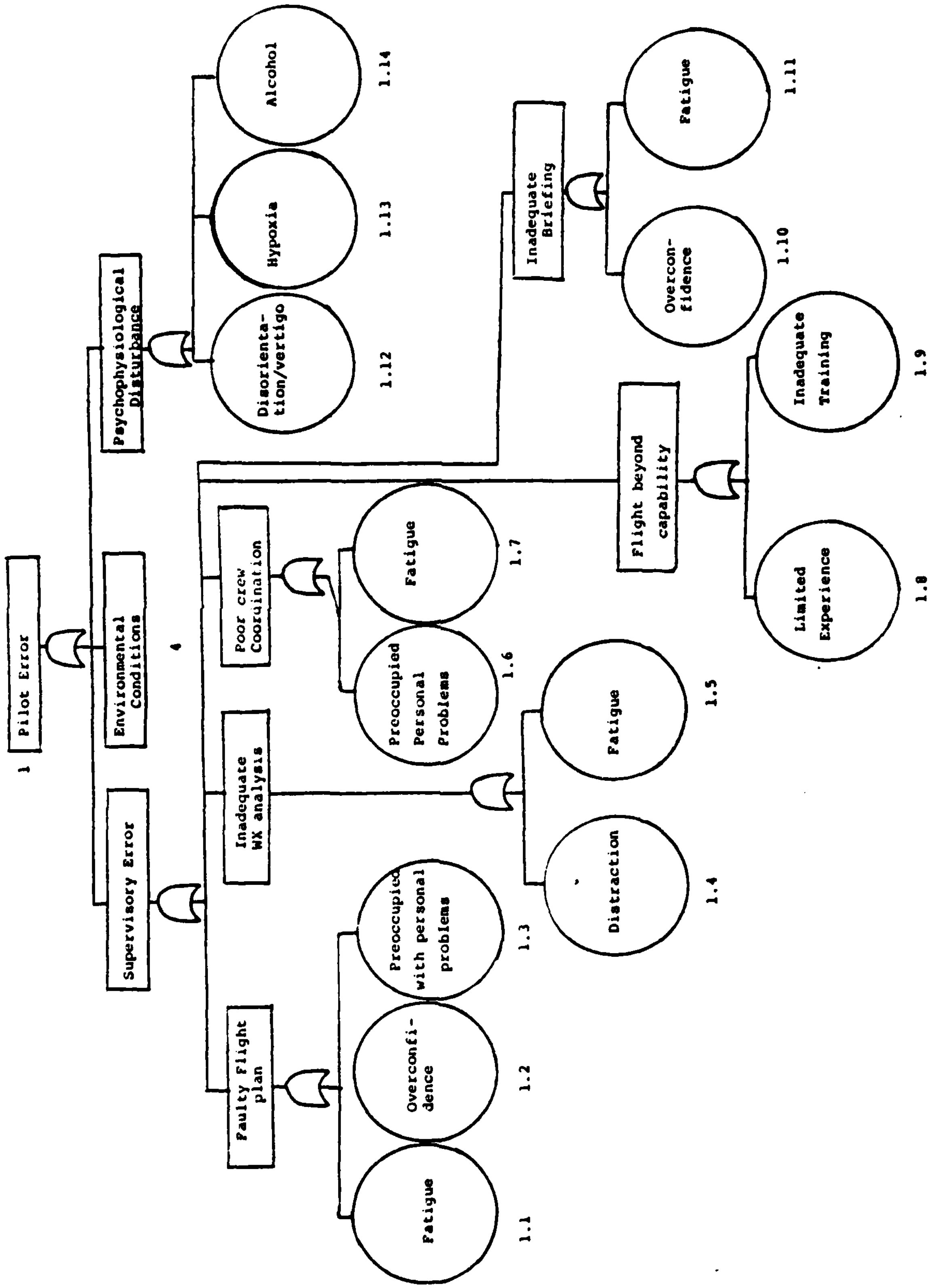

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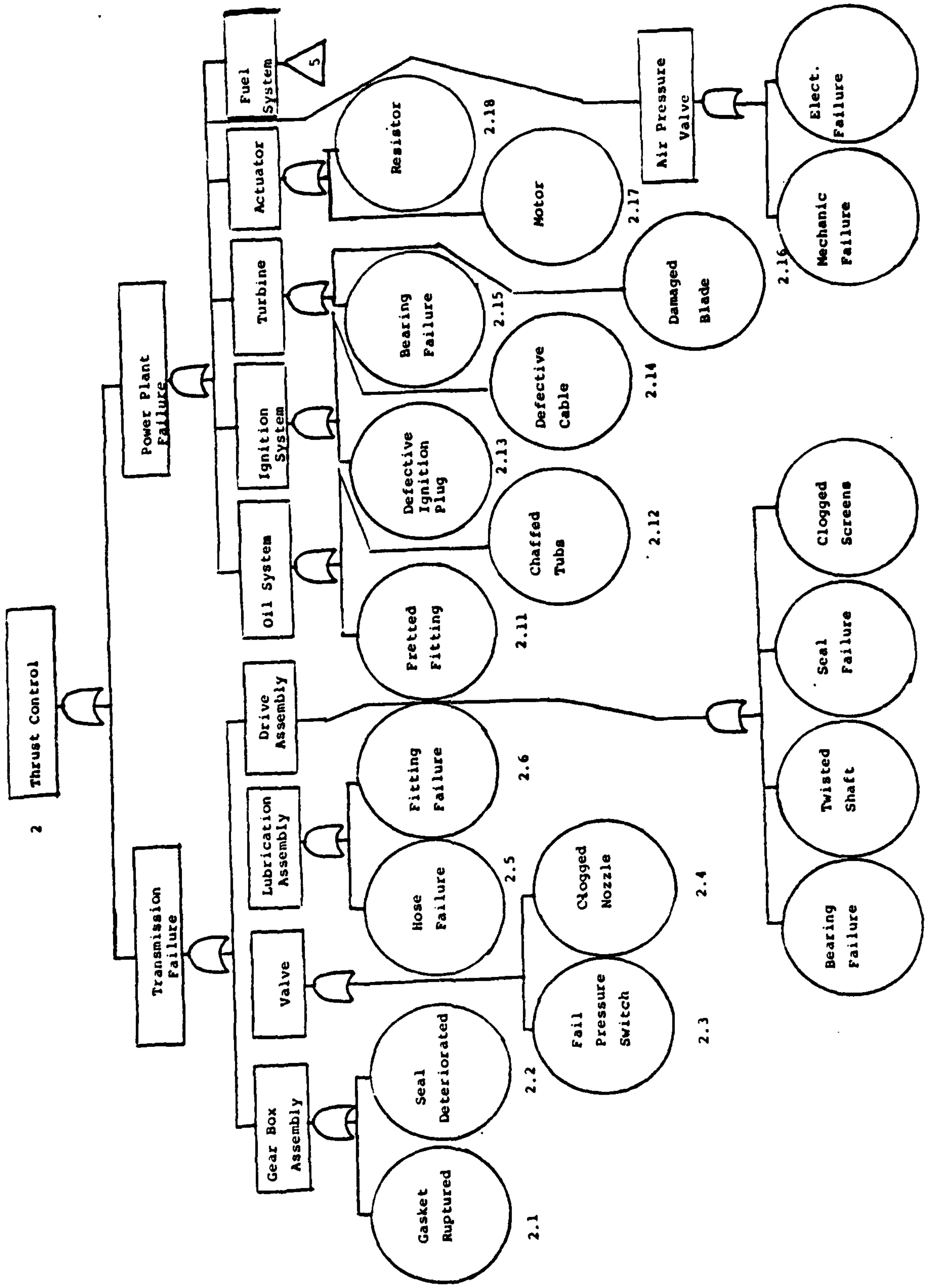
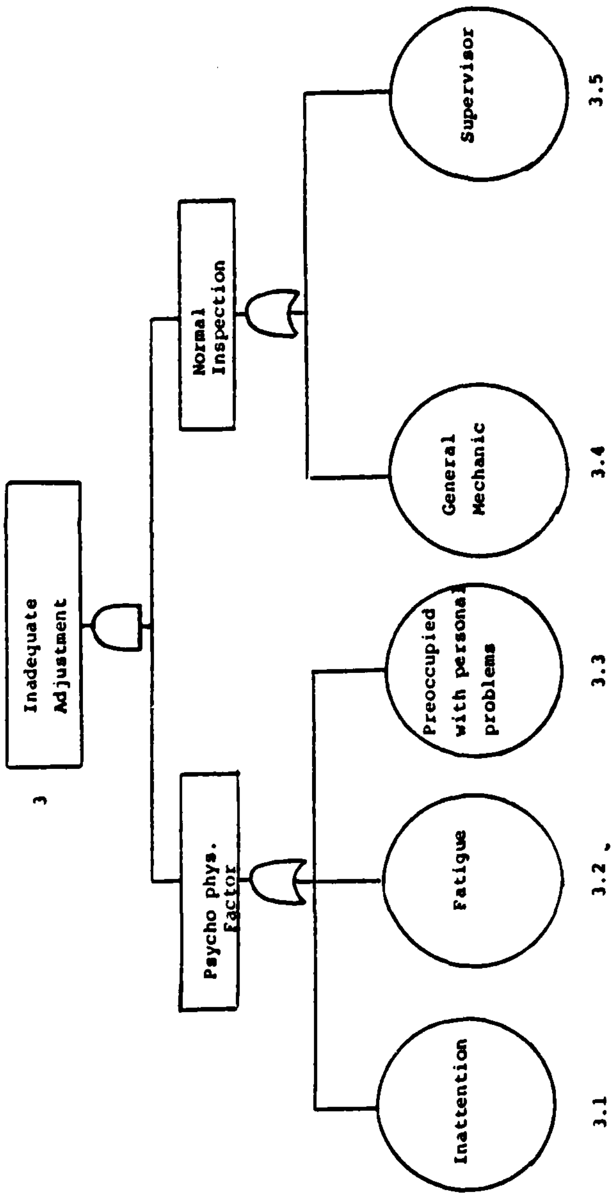
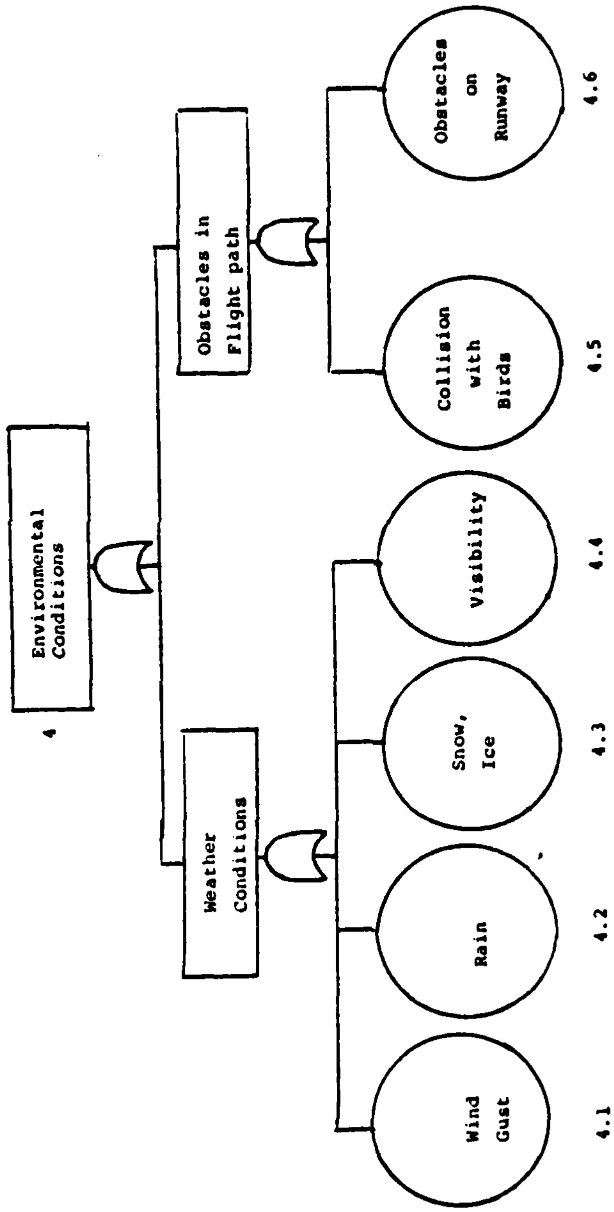



Inadequate Adjustment
3
Normal Inspection
Psycho phys. Factor
Supervisor
3.5
General Mechanic
3.4
Preoccupied with personal problems
3.3
Fatigue
3.2
Inattention
3.1

APPENDIX B CONTINUED



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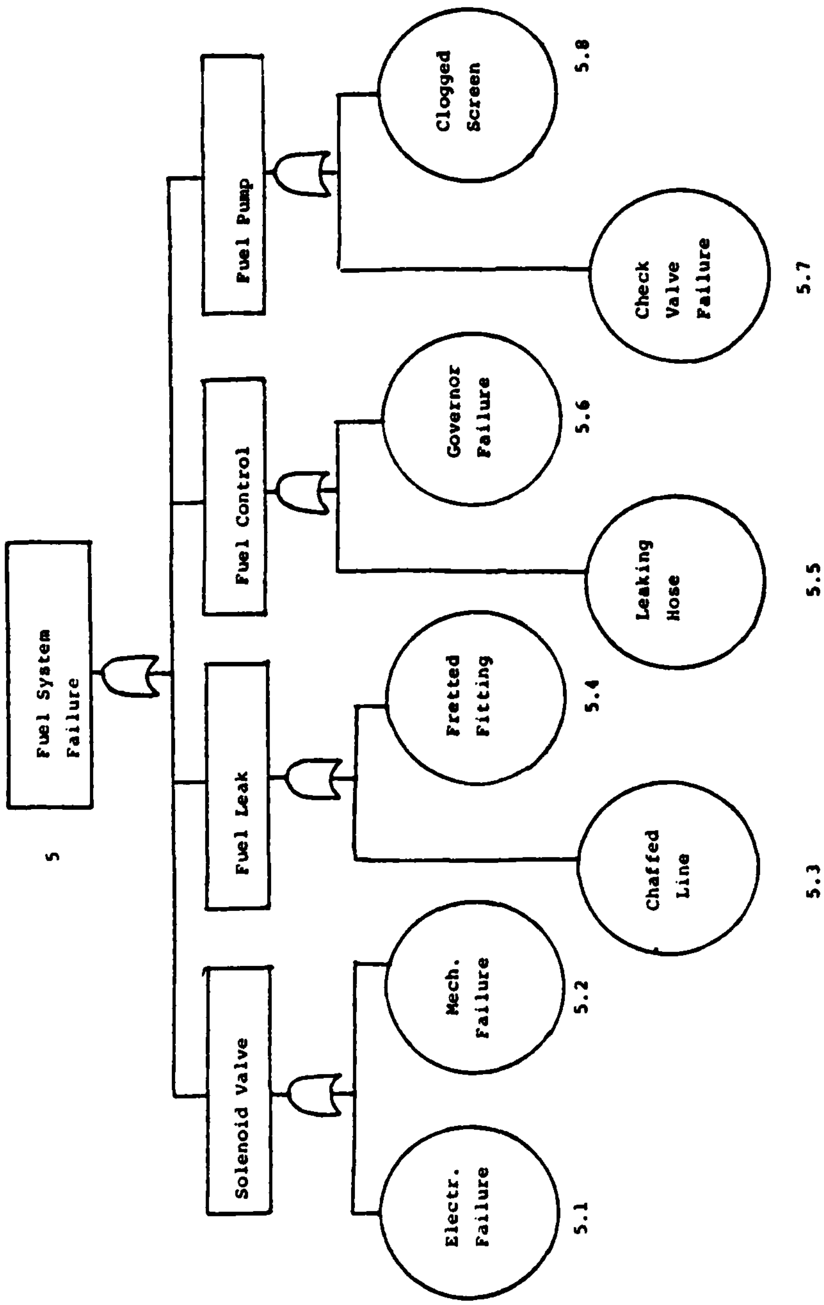

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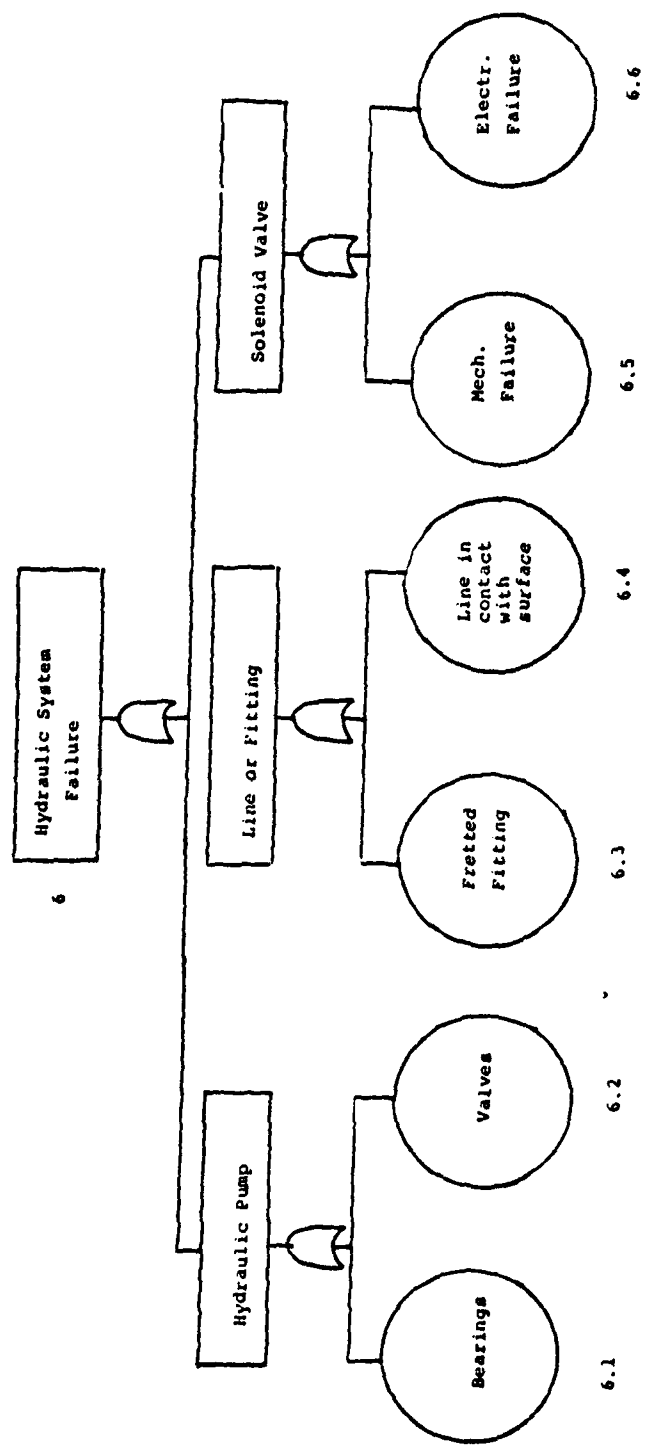


APPENDIX C

REPORTING FORMATS FOR DATA COLLECTION

GROUND MISHAP REPORT

(Complete only applicable items)

1. ORGN, COMD & BASE SUBMITTING RPRT

2. MISHAP TYPE: OPERATIONAL / NON-OPL

3. SEVERITY CLASS: A / B / C / HAP

4. BASE, BASE CODE & RPRT SERIAL NO.

5. MISHAP CATEGORY: INDUSTRIAL / COMBAT TNG / PMV / SPV / COML CARRIER / CONTRACTOR / MARINE / GMV / SPORT/RECRN / MISCELLANEOUS

6. DATE OF MISHAP: YEAR / MONTH / DAY / DAY OF WEEK

7. MISHAP LOCATION: ON BASE / OFF BASE / DESCRIBE

8. WEATHER ☐ NOT A FACTOR: CLEAR / RAIN / SNOW / OTHER (Explain) / FOG

9. MISHAP INVOLVED: NA / NATURAL PHENOMENA (Specify) / FIRE/EXPLOSION

10. LOCAL TIME

11. LIGHT CONDITION: DAY / NIGHT / DAWN / DUSK

12. SYNOPSIS (What happened and why)

13. PERSON REPORTED AS — NO.

A. NAME, GRADE AND SSAN

B. ASSIGNED ORGN, BASE AND COMD

C. DUTY AFSC/ JOB SERIES

D. AGE

E. SEX: MALE / FEMALE

F. COMPONENT ☐ NOT APPLICABLE

(1) MILITARY: AF ACTIVE / OTHER US MIL (Specify) / FOREIGN MIL (Specify)

(2) CIVILIAN: DAF / NAF (Ex-mil) / FOREIGN / YOUTH/STU

G. STATUS: (1) ON DY / OFF DY; (2) LEAVE / TDY / ENR. PCS / ABCL

H. PRE-EXISTING PHYSICAL/MENTAL LIMITATIONS ☐ NONE: ALCOHOL / FATIGUE / EMOTIONAL / HEARING / EYESIGHT / PHYSICAL / ILL/SICK / RX DRUG / DRUGS / OTHER (Specify)

I. OFFICERS ONLY: RATED / NON-RATED

J. DISABILITY CLASSIFICATION ☐ INJURY ☐ ILLNESS ☐ NONE: PERM PART / FATAL / WORKDAYS REST. (Enter no.) / PERM TOTAL / TREAT/REL. / WORKDAYS LOST (Enter no.)

K. INJURY TYPE & LOCATION

L. INJURY COST

M. PROTECTIVE EQUIPMENT: (1) USED / (2) REQUIRED BUT NOT USED (Enter item and authority)

N. INVOLVED: DIRECTLY / INDIRECTLY

O. JOB TRAINING: REQUIRED YES / NO; ADEQUATE YES / NO; DATE COMPLETED

P. SAFETY TNG (Identify tng and give completion dates)

Q. UNSAFE ACT

R. ACTIVITY AT TIME OF MISHAP

S. EXPERIENCE WITH TASK: 0 - 1 YEAR / 1 - 3 YEARS / OVER 3 YEARS

14. VEHICLE/AIRCRAFT REPORTED NO.

A. PMV: PERSONAL EXPENSE / PMV-GOVT REIMB / RENT-GOVT REIMB

B. VEHICLE: AUTOMOBILE / MOTORCYCLE / OTHER (Specify)

C. SPEED: POSTED / ACT/EST

D. YR.

E. MAKE

F. TYPE

G. CITATIONS ISSUED (Specify)

H. VEHICLE ACTIVITY/ROAD SURFACE

I. OPERATION: ON ROAD / OFF ROAD

J. DAMAGE COST

15. USAF PROPERTY DAMAGE

A. TYPE/DESIGNATION PROPERTY DAMAGED

B. OWNER (MAJCOM)

C. DESCRIBE DAMAGE

D. MANHOURS TO REPAIR

E. LABOR COST

F. MATERIAL COST

G. TOTAL COST

16. TOTAL MISHAP COST

A. AF INJURY

B. AF PPTY DAMAGE

C. NON-AF PPTY DAMAGE

D. TOTAL AF LOSS

17. SOURCE OF REPORT DATA

18. USAF REPORTING OFFICIAL (Type name, grade and title)

19. DATE

20. RESPONSIBLE COMDR/FUNCTIONAL MGR (Type name, grade and title)

21. SIGNATURE

AIRCRAFT FLIGHT MISHAP REPORT

(To be filled out for principal aircraft involved. Appropriate items only should be filled out on secondary aircraft.)

1 MISHAP CLASS	2 ACFT MDS & SERIAL NO	3 DATE	4 UNIT CONTROL NO	5 ACFT ASSIGNMENT/STATUS CODE
☐ A ☐ B ☐ C ☐ DEST				

PILOT(S) INVOLVED (FLIGHT CREW)[1]

6. OPERATOR AT CONTROLS

A. LAST NAME, INITIALS	B. COMPONENT

C. POSITION IN AIRCRAFT AT TIME OF MISHAP: ☐ FRONT SEAT ☐ LEFT SEAT ☐ REAR SEAT ☐ RIGHT SEAT ☐ JUMP SEAT | D. NATIONALITY | E. AGE

F. MAJCOM, NAF, DIV, WG, SQ ASSIGNED	G. MAJCOM, NAF, DIV, WG, SQ ATTACHED FOR FLYING

7. OTHER PILOT

A. LAST NAME, INITIALS	B. COMPONENT

C. POSITION IN AIRCRAFT AT TIME OF MISHAP: ☐ FRONT SEAT ☐ LEFT SEAT ☐ REAR SEAT ☐ RIGHT SEAT ☐ JUMP SEAT | D. NATIONALITY | E. AGE

F. MAJCOM, NAF, DIV, WG, SQ ASSIGNED	G. MAJCOM, NAF, DIV, WG, SQ ATTACHED FOR FLYING

8. OTHER PILOT

A. LAST NAME, INITIALS	B. COMPONENT

C. POSITION IN AIRCRAFT AT TIME OF MISHAP: ☐ FRONT SEAT ☐ LEFT SEAT ☐ REAR SEAT ☐ RIGHT SEAT ☐ JUMP SEAT | D. NATIONALITY | E. AGE

F. MAJCOM, NAF, DIV, WG, SQ ASSIGNED	G. MAJCOM, NAF, DIV, WG, SQ ATTACHED FOR FLYING

9. OTHER PILOT

A. LAST NAME, INITIALS	B. COMPONENT

C. POSITION IN AIRCRAFT AT TIME OF MISHAP: ☐ FRONT SEAT ☐ LEFT SEAT ☐ REAR SEAT ☐ RIGHT SEAT ☐ JUMP SEAT | D. NATIONALITY | E. AGE

F. MAJCOM, NAF, DIV, WG, SQ ASSIGNED	G. MAJCOM, NAF, DIV, WG, SQ ATTACHED FOR FLYING

10. CLEARANCE

FROM	TO

☐ VFR ☐ IFR ☐ LOCAL ☐ PT TO PT ☐ DIRECT ☐ AIRWAYS ☐ NO CLEARANCE ☐ NA

11. DURATION OF FLIGHT		12. TYPE OF MISSION	13. ALTITUDE/ELEVATION
HOURS	TENTHS		

14. PHASE OF OPERATION	15. TYPE OF MISHAP

16. METEOROLOGICAL CONDITIONS ☐ VMC ☐ SIMULATED IMC ☐ TRANSITION ☐ IMC ☐ ON TOP ☐ VFR IN IMC CONDITIONS

17. AIRFIELD DATA APPLICABLE TO TAKEOFF AND LANDING MISHAPS OCCURRING WITHIN 2 MILES OF AIRFIELD

A. FIELD ELEVATION *(Feet)*	B. COMPOSITION OF RUNWAY ☐ ASPHALT ☐ CONCRETE ☐ OTHER *(Specify)*

C. LENGTH OF RUNWAY *(Feet)*	D. RUNWAY HEADING	E. DISTANCE OF TOUCHDOWN FROM RUNWAY *(Feet)*	F. SURFACE CONDITION ☐ DRY ☐ WET	OTHER *(Specify)*

G. LENGTH OF OVERRUN	H. COMPOSITION OF OVERRUN *(Specify)*	I. BARRIER TYPE	USED ☐ YES ☐ NO	LOCATION

J. CONDITIONS AFFECTING OCCURENCE *(For example, type of instrument or lighting approach used, obstructions, barrier, airspeed, gross weight, forced landing)*

[1] *If more than four pilots are involved (Flight Crew) report same information required on additional sheet for each.*

AIRCRAFT MAINTENANCE AND MATERIEL REPORT

1. AIRCRAFT SERIAL NUMBER	2. MISSION DESIGN AND SERIES (MDS)

3. HISTORICAL DATA

AIRCRAFT		DEFICIENT PART COMPONENT OR ACCESSORY								
AIR FORCE ACCEPTANCE DATE		NOUN								
TOTAL FLIGHT HOURS		PART NUMBER								
LAST OVERHAUL DATE		T.O. REFERENCE								
OVERHAULING ACTIVITY (*Name & Loc*)		FIGURE								
HOURS SINCE OVERHAUL		INDEX								
HOURS SINCE LAST SCHEDULED INSP.		WORK UNIT CODE								
DATE OF LAST SCHEDULED INSPECTION		TDR REQUESTED	YES		NO		YES		NO	
TYPE OF LAST SCHEDULED INSPECTION		MDR SUBMITTED	YES		NO		YES		NO	
DATE ASGNED PRESENT ORGN.		MDR NUMBER								
ORGN. TRANSFERRED FROM		MIP NUMBER								

ENGINE
(Complete a Column for each Engine)

INSTALLED POSITION				
ENGINE MODEL AND SERIES				
ENGINE SERIAL NUMBER				
TOTAL ENGINE HOURS				
NUMBER OF MAJOR OVERHAULS				
HRS SINCE LAST MAJOR OVERHAUL				
DATE OF LAST OVERHAUL				
OVERHAUL ACTIVITY				
DATE LAST INSTALLED				
HOURS SINCE LAST INSTALLED				
DATE OF LAST SCHEDULED INSPECTION				
TYPE OF LAST SCHEDULED INSPECTION				
FUEL (*Type & Octane Rating*)				
TDR REQUESTED				

4. SOAP SAMPLES
(Engine, CSD, Gearbox or APU failure of which occurred or was suspected)

ITEM AND SERIAL NUMBER

HOURS SINCE O/H	HOURS SINCE OIL CHANGE	FE	CR	AG	AL	CU	SN	MG	TI			HOURS SINCE O/H	HOURS SINCE OIL CHANGE	FE	CR	AG	AL	CU	SN	MG	TI		

5. DAMAGED AIRCRAFT
(Furnish complete damage information under Tab "L". See AF Form 711b)

DAMAGE TO AIRCRAFT	MANHOURS TO REPAIR	COST (ESTIMATE)
☐ DESTROYED OR DAMAGED BEYOND ECONOMICAL REPAIR ☐ SUBSTANTIAL ☐ MINOR ☐ LESS THAN MINOR OR NONE		

6. FIRE DATA
(To be completed when fire or chemical explosion occurs, not resulting from ground impact. Indicate: P - Probable or K - Known, in squares)

A. MATERIEL FAILURE CAUSING THE FIRE				B. IGNITION SOURCE				C. COMBUSTIBLE MATERIAL			
ELECTRICAL SYSTEM		PROPULSION SYSTEM		ELECTRICAL SYSTEM		STATIC ELECTRICITY/LIGHTNING		CARGO		HYDRAULIC FLUID	
FUEL SYSTEM		BLEED AIR SYSTEM		PNEUMATIC SYSTEM		OTHER (*Specify*)		ELECTRICAL INSULATION		LUBRICATING OIL	
HYDRAULIC SYSTEM		OTHER (*Specify*)		PROPULSION SYSTEM				EXPLOSIVES		OTHER (*Specify*)	
PNEUMATIC SYSTEM		UNKOWN		BLEED AIR		UNKNOWN		FUEL		UNKNOWN	

7. LOCATION OF INITIAL FIRE

	KNOWN	PROBABLE		KNOWN	PROBABLE		KNOWN	PROBABLE
BAGGAGE COMPARTMENT			AFT OF FIREWALL			WHEEL WELL		
BOMB BAY			FORWARD OF FIREWALL			CARGO-PASSENGER COMPARTMT.		
COCKPIT OR CREW QUARTERS			ROCKET POD			OTHER (*Specify*)		
ENGINE SECTION			TIRE, WHEEL OR BRAKE			UNKNOWN ☐		

8. MISCELLANEOUS CHEMICAL EXPLOSION DATA

	KNOWN	PROBABLE		KNOWN	PROBABLE
INITIAL IGNITION OCCURRED IN AN EXPLOSIVE MANNER PRIOR TO GROUND IMPACT.			INTENSITY OF EXPLOSION WAS SUFFICIENT TO CAUSE OR APPRECIABLY CONTRIBUTE TO IN-FLIGHT AIRFRAME BREAK-UP.		
EXPLOSION OCCURRED AFTER FIRE & BEFORE GRD IMPACT.			OTHER SIGNIFICANT DATA (*Specify*)		
EXPLOSION OCCURRED SUBSEQUENT TO GROUND IMPACT.			UNKNOWN OR NOT AVAILABLE		

III. PSYCHOPHYSIOLOGICAL AND ENVIRONMENTAL FACTORS

INSTRUCTIONS: Complete on all occupants of aircraft, all injured persons, and all persons possibly contributing to the cause of the mishap. Supervisory factors attributed to persons not in the aircraft and such factors as design or weather should be reported only for the person in primary control of the aircraft. Factors contributing to injury during mid-air collisions, crash landings, ditchings, etc., are to be considered part of survival phase. Use codes at right to show only those factors present or contributing in each phase.

PHASES OF MISHAP
- A - ACCIDENT
- E - ESCAPE
- L - LANDING
- S - SURVIVAL (*Includes parachute landings*)
- R - RESCUE

FACTOR IMPORTANCE
- D - DEFINITELY CONTRIBUTED
- S - SUSPECTED FACTOR
- P - CONDITION PRESENT BUT DID NOT CONTRIBUTE TO ACCIDENT OR INJURY

FACTORS		A	E	L	S	R
1. SUPERVISORY FACTORS						
INADEQUATE BRIEFING	101					
ORDERED/LED ON FLIGHT BEYOND CAPABILITY	102					
POOR CREW COORDINATION	103					
OTHER (*Specify*)	199					
2. PRE-FLIGHT FACTORS						
FAULTY FLIGHT PLAN	201					
FAULTY PRE-FLIGHT OF AIRCRAFT	202					
FAULTY PREPARATION OF PERSONAL EQUIP.	203					
HURRIED DEPARTURE	204					
DELAYED DEPARTURE	205					
INADEQUATE WEATHER ANALYSIS	206					
OTHER (*Specify*)	299					
3. EXPERIENCE/TRAINING FACTORS						
INADEQUATE TRANSITION	301					
LIMITED TOTAL EXPERIENCE	302					
LIMITED RECENT EXPERIENCE	303					
FAILURE TO USE ACCEPTED PROCEDURES	304					
OTHER (*Specify*)	399					
4. DESIGN FACTORS						
DESIGN OF INSTRUMENTS, CONTROLS	401					
LOCATION OF INSTRUMENTS, CONTROLS	402					
FAILURE OF INSTRUMENTS, CONTROLS	403					
COCKPIT LIGHTING	404					
RUNWAY LIGHTING	405					
LIGHTING OF OTHER AIRCRAFT	406					
PERSONAL EQUIPMENT INTERFERENCE	407					
WORKSPACE INCOMPATIBLE WITH MAN	408					
OTHER (*Specify*)	499					
5. COMMUNICATIONS PROBLEMS						
MISINTERPRETED COMMUNICATIONS	501					
DISRUPTED COMMUNICATIONS	502					
LANGUAGE BARRIER	503					
NOISE INTERFERENCE	504					
OTHER (*Specify*)	599					
6. PSYCHOPHYSIOLOGICAL FACTORS						
FOOD POISONING	601					
MOTION SICKNESS	602					
OTHER ACUTE ILLNESS	603					
OTHER PRE-EXISTING DISEASE/DEFECT	604					
GET-HOMEITIS	605					
HANGOVER	606					
SLEEP DEPRIVATION, FATIGUE	607					
FATIGUE, OTHER	608					
MISSED MEALS	609					
DRUGS PRESCRIBED BY MEDICAL OFFICER	610					
DRUGS, OTHER	611					
ALCOHOL	612					

FACTORS		A	E	L	S	R
VISUAL ILLUSIONS	613					
UNCONSCIOUSNESS	614					
DISORIENTATION/VERTIGO	615					
HYPOXIA	616					
HYPERVENTILATION	617					
DYSBARISM	618					
CARBON MONOXIDE POISONING	619					
BOREDOM	620					
INATTENTION	621					
CHANNELIZED ATTENTION	622					
DISTRACTION	623					
PREOCCUPATION WITH PERSONAL PROBLEMS	624					
EXCESSIVE MOTIVATION TO SUCCEED	625					
OVERCONFIDENCE	626					
LACK OF SELF-CONFIDENCE	627					
LACK OF CONFIDENCE IN EQUIPMENT	628					
APPREHENSION	629					
PANIC	630					
OTHER (*Specify*)	699					
7. ENVIRONMENTAL FACTORS						
ACCELERATION FORCES, IN-FLIGHT	701					
ACCELERATION FORCES, IMPACT	702					
DECOMPRESSION	703					
VIBRATION	704					
GLARE	705					
SMOKE, FUMES, ETC.	706					
HEAT	707					
COLD	708					
WIND BLAST	709					
VIS. RESTR.-WEATHER, HAZE, DARKNESS	710					
VIS. RESTR.-ICING, WINDOWS FOGGED, ETC.	711					
VIS. RESTR.-DUST, SMOKE, ETC., IN ACFT.	712					
WEATHER, OTHER THAN VISIBILITY RESTR.	713					
OTHER (*Specify*)	799					
8. OTHER FACTORS TO BE CONSIDERED						
HABIT INTERFER., USED WRONG CONTROL	801					
CONFUSION OF CONTROLS, OTHER	802					
MISREAD INSTRUMENT(S)	803					
MISINTERPRETED INSTRUMENT READING	804					
MISLED BY FAULTY INSTRUMENT	805					
VISUAL RESTR. BY EQUIP. STRUCTURES	806					
TASK OVERSATURATION	807					
INADEQUATE COORDINATION OF TIMING	808					
MISJUDGED SPEED OR DISTANCE	809					
SELECTED WRONG COURSE OF ACTION	810					
DELAY IN TAKING NECESSARY ACTION	811					
VIOLATION OF FLIGHT DISCIPLINE	812					
NAVIGATIONAL ERROR	813					
INADVERTENT OPER., SELF INDUCED	814					
INADVERTENT OPER. MECHANICALLY INDUC	815					
OTHER (*Specify*)	899					

NAME OF INDIVIDUAL	SSAN

IV. PERSONAL DATA											
1. ROLE OF THIS INDIVIDUAL IN THE CAUSE OF THIS ACCIDENT											
A. PRIMARY						B. CONTRIBUTING					0 - NONE
	1. DEF.		2. PROB.		3. POSS.		4. DEF.		5. PROB.		6. POSS.	9 - UNKNOWN

C. DUTY OR ROLE AT TIME OF ACCIDENT

2. BACKGROUND DATA *(Complete for all pilots and others who possibly contributed to mishap.)*

A. DATE LAST LEAVE ENDED *(Day-Mo.-Yr.)*	B. DAYS DURATION LAST LEAVE	C. TYPE OF LAST LEAVE TAKEN					
		1. ORD.	3. REENLIST.	5. SICK OR CONVALESCENT	6 - DELAY ENR.		
		2. EMERG.	4. GRADUATION		9 - UNKNOWN		

D. DATE OF LAST PREVIOUS FLIGHT *(Day-Mo.-Yr.)*	E. HOURS FLOWN IN LAST 24 HOURS	F. HOURS FLOWN IN LAST 48 HOURS	G. SORTIES FLOWN IN LAST 24 HOURS
H. SORTIES FLOWN IN LAST 48 HOURS	I. HOURS WORKED IN LAST 24 HOURS	J. HOURS WORKED IN LAST 48 HOURS	K. HOURS SLEPT IN LAST 24 HOURS

L. HOURS SLEPT IN LAST 48 HOURS	M. HOURS CONTINUOUS DUTY PRIOR TO MISHAP	N. HRS. CONTINUOUSLY AWAKE PRIOR TO MISHAP	O. HOURS DURATION OF LAST SLEEP PERIOD	P. TIME IN COCKPIT PRIOR TO FLIGHT *(Hrs., Min.)*
Q. DATE LAST PREVIOUS FLT. THIS MODEL	R. DURATION PREVIOUS FLT. THIS MODEL	DEPLOYED UNITS: S. DATE DEPLOYED	T. NO. DAYS IN AREA	U. TIME SINCE DEPLOYMENT

3. PHYSIOLOGICAL AND VERTIGO TRAINING *(For all personnel)*

TYPE OF TRAINING ACCOMPLISHED	PLACE TRAINING ACCOMPLISHED	COMPLETED MONTH	COMPLETED YEAR	ROLE [1] IN MISHAP

4. ANTHROPOMETRIC DATA

A. DATE OF BIRTH *(Day-Month-Year)*	D. SITTING HEIGHT *(Inches)*	G. BUTTOCK-KNEE LENGTH *(Inches)*
B. HEIGHT *(Inches)*	E. TRUNK HEIGHT *(Inches)*	H. LEG LENGTH *(Inches)*
C. WEIGHT *(Lbs.)*	F. FUNCTIONAL REACH *(Inches)*	I. SHOULDER WIDTH (BIDELTOID) *(Inches)*

5. TOTAL YEARS OF FORMAL EDUCATION	6. GRADUATION FROM UNDERGRADUATE FLIGHT TRAINING	
	BASE	DATE

7. AVIATION SCHOOLS ATTENDED SINCE GRADUATION *(Include date of completion)*

8. FLYING EXPERIENCE
(Attach copy of individual flying experience as outlined by AFR 127-2)

A. TOTAL FLYING HOURS *(Including AF time, student and other accredited time)*	C. TOTAL TIME THIS AIRCRAFT
B. TOTAL JET TIME	D. TOTAL WEATHER INSTRUMENT HOURS

FIRST PILOT AND INSTRUCTOR PILOT HRS.	30 DAYS	60 DAYS	90 DAYS	TOTAL
ALL AIRCRAFT	E.	H.	K.	N.
THIS AIRCRAFT	F.	I.	L.	O.
SORTIES THIS AIRCRAFT	G.	J.	M.	P.

Q. ORIGINAL AERONAUTICAL RATING AND DATE	R. PRESENT AERONAUTICAL RATING AND DATE	DATE OF LAST CHECK: S. INSTRUMENT	T. PROFICIENCY	U. AFSC
				PRIMARY
				DUTY

9. AVIATION SERVICE CODE AND FLYING ACTIVITY CATEGORY (1A/1, 1J/1, ETC.)

CURRENT	FROM	
PREVIOUS	FROM	TO
PREVIOUS	FROM	TO
PREVIOUS	FROM	TO
NAME OF INDIVIDUAL		SSAN

[1] For role in mishap (Item 3), the following codes will be used)

0 - No importance
1 - Training definitely helped
2 - Training possibly helped
3 - Lack of training definite factor
4 - Lack of training possible factor
9 - Unknown

LIFE SCIENCES REPORT OF AN INDIVIDUAL INVOLVED IN AN AF ACCIDENT/INCIDENT
SECTION A, AIRCRAFT ACCIDENT/INCIDENT
(THIS FORM IS AFFECTED BY THE PRIVACY ACT OF 1974. SEE LAST PAGE)

I. FLIGHT DATA

1. TERRAIN CLEARANCE AT TIME OF EMERGENCY (Feet)
2. CABIN ALTITUDE AT TIME OF EMERGENCY (Feet)
3. TIME AT CABIN ALTITUDE — HOURS | MINUTES
4. AMBIENT ALTITUDE AT TIME OF EMERGENCY (Feet) MSL
5. TIME AT AMBIENT ALTITUDE — HOURS | MINUTES
6. PLACE IN FORMATION — 0-SINGLE AIRCRAFT | L-LEAD | W-WING | Y-OTHER (Specify)
7. CLOUD CONDITIONS — 0-CLEAR | 1-OVERCAST | 2-UNDERCAST | 3-IN CLOUDS | 4-IN AND OUT OF CLOUDS | 8-OTHER (Specify)
8. HORIZON — 1-DISTINCT | 2-OBSCURED | 8-OTHER (Specify)
9. DURATION OF FLIGHT — HOURS | MINUTES

II. MEDICAL INFORMATION

1. DEGREE OF INJURY — 1-NONE | 3-MAJOR | 5-MISSING LAND | 7-MISSING UNKNOWN | 2-MINOR | 4-FATAL | 6-MISSING WATER | 8-MINIMAL
2. DAYS HOSPITALIZED
3. DAYS IN QUARTERS
4. GROUNDED-DURATION (Days)
5. UNCONSCIOUS DURATION — HOURS | MINUTES
6. INJURIES INCURRED DURING MISHAP *(Use standard nomenclature and coding for Nature and Location of Injury (Line 1) and External Cause (Line 2). Also indicate and code Location, Phase of Mishap, and Problems (Line 3). See AFM 127-2 for specific instructions.)* — CODE

	CODE			
A. NATURE AND LOCATION				
B. EXTERNAL CAUSE				
C. LOCATION, PHASE OF MISHAPS, AND PROBLEMS				
A. NATURE AND LOCATION				
B. EXTERNAL CAUSE				
C. LOCATION, PHASE OF MISHAPS, AND PROBLEMS				
A. NATURE AND LOCATION				
B. EXTERNAL CAUSE				
C. LOCATION, PHASE OF MISHAPS, AND PROBLEMS				
A. NATURE AND LOCATION				
B. EXTERNAL CAUSE				
C. LOCATION, PHASE OF MISHAPS, AND PROBLEMS				
A. NATURE AND LOCATION				
B. EXTERNAL CAUSE				
C. LOCATION, PHASE OF MISHAPS, AND PROBLEMS				

7. LABORATORY TESTS	TISSUE TESTED	METHOD USED	LAB TESTING	RESULT	CODES (Leave blank)
CARBON MONOXIDE					
ALCOHOL					
LACTIC ACID					
OTHER (Specify)					

8. X-RAY RESULTS

9. DISEASES/DEFECTS PRESENT AT TIME OF MISHAP — DIAGNOSIS	METHOD OF DISCOVERY: ANNUAL PHYS	SICK CALL	AUTOPSY	OTHER	WAIVERS (As applicable): AUTHORITY	DATE: MO.	YEAR

10. AUTOPSY CONDUCTED BY — M-MILITARY PATHOLOGIST | F-FLIGHT SURGEON | C-CIVILIAN PATHOLOGIST | Y-OTHER | Z-NONE
11. MATERIAL SUBMITTED TO AFIP — 0-NONE | 1-AUTOPSY REPORT | 2-FROZEN TISSUE | 3-PICTURES | 4-FIXED TISSUE
12. REMARKS OR CONTINUATION OF ABOVE
13. HUMAN RELIABILITY POSITION — ☐ YES ☐ NO | CONTROLLED | CRITICAL

NAME OF INDIVIDUAL		SSAN	DATE OF MISHAP	LEAVE BLANK
ASSIGNED UNIT	DATE OF ASSIGNMENT	BASE	COMMAND	
AIRCRAFT MDS		AERONAUTICAL RATING		

IV. TRAINING RELATED TO THIS ACCIDENT/INCIDENT

AFSC (or other) TRAINING	NAME OF COURSE OR OJT	DATES ATTENDED	APTITUDE [illegible] APPLICABLE

V. PERSONAL AND PROTECTIVE EQUIPMENT *(Specify all applicable items of equipment on appropriate line and indicate all types of clothing and any other equipment that influenced operation)*

ITEM	NOMENCLATURE AND MODEL DESIGNATION	RE-QUIRED	AVAIL-ABLE	USED	NEEDED	DIS-CARDED	LOST	FAILED	PROBLEMS
HEAD PROTECTION									
EYE PROTECTION									
EAR PROTECTION									
BREATHING AID									
CLOTHING WORN									
GLOVES									
FOOTWEAR									
BODY RESTRAINTS									
COMMUNICATIONS									
SEAT &/OR OTHER EQUIP.									
ESCAPE									
TYPE WARNING ISSUED									
OTHER *(Specify)*									

VI. VEHICLE/EQUIPMENT

MAKE	MODEL	NO. OF DOORS	INSPECTION CERTIFICATE
PADDED DASH	TINTED WINDSHIELD	RECESSED STEERING WHEEL	DATE ______
1-YES / 0-NO	1-YES / 0-NO	1-YES / 0-NO	MILITARY ______ CIVIL ______

MECHANICAL CONDITION *(Indicate by (s) Satisfactory or (u) Unsatisfactory)*

	A-BRAKES		B-TIRES		C-LIGHTS		D-STOP LIGHTS
	E-DIRECTIONAL SIGNALS		F-REARVIEW MIRROR		G-EXHAUST SYSTEM		H-STEERING MECHANISM
	J-W/SHIELD WIPERS		Y-OTHER *(Specify)*				

VII. CAUSE OF INJURY OR DEATH

	A-STRUCK STEERING COLUMN		B-WINDSHIELD		C-VISOR		D-DISPLACED OBJECT
	E-DOORFRAME		F-INTRUDING OBJECT		G-FIRE		H-DROWNED
	J-PEDESTRIAN STRUCK BY VEHICLE		K-EXPOSURE		L-EXPLOSION		M-STRUCK SUBMERGED OBJECT
	Y-OTHER						

VIII. ACCIDENT AREA AND CONDITIONS *(Specify all applicable items)*

	TIME OF DAY (Local)		1-DAY		2-NIGHT		3-LIGHTING		1-SATISFACTORY		0-UNSATISFACTORY

	TYPE OF SURFACE		ROAD CONDITION		TYPE OF ROAD		ROAD CONFIGURATION		WEATHER
	1-CONCRETE		1-DRY		1-ONE LANE		1-STRAIGHT		1-CLEAR
	2-MACADAM		2-ICE		2-TWO LANE		2-CURVE		2-CLOUDY
	3-BRICK		3-WET		3-THREE LANE		3-BANK		3-RAIN
	4-LOOSE GRAVEL		4-SNOW		4-FOUR OR MORE LANES		4-CURVE AND BANK		4-SNOW
	5-DIRT		5-SLUSH		5-DIVIDED TWO LANE		5-INTERSECTION		5-SLEET
			6-MUD		6-DIVIDED MORE THAN TWO LANE				6-FOG
									7-HAZE
	9-OTHER		9-OTHER		9-OTHER		9-OTHER		9-OTHER

REMARKS

IX. COMMENTS

THIS SECTION INCLUDES MEDICAL, PERSONAL AND [illegible] WHICH HAVE A DIRECT BEARING ON THE ACCIDENT AND/OR INJURY CAUSATION. THE ANALYSIS OF ALL FACTORS BY MEDICAL OFFICERS, WITH APPROPRIATE RECOMMENDATIONS BASED ON FIRST HAND OBSERVATIONS IS DESIRED. INCLUDE [illegible] OF ACTIVITIES OF PREVIOUS [illegible] FOR ALL PERSONS POSSIBLY CONTRIBUTING TO MISHAP.) *(Continue on additional sheet if necessary)*

DATE	TYPED NAME, [illegible] OFFICER	[illegible] *(Optional)*

NAME OF INDIVIDUAL	[illegible]

VI. EGRESS - SURVIVAL GENERAL *(Complete for all individuals)*

1. LOCATION IN AIRCRAFT

A.

- 1 - COCKPIT OR PILOT'S COMPARTMENT
- 2 - NAVIGATOR'S/ENGINEER'S COMPARTMENT
- 3 - PASSENGER'S COMPARTMENT *(Single deck)*
- 4 - PASSENGER'S COMPARTMENT *(Upper deck)*
- 5 - PASSENGER'S COMPARTMENT *(Lower deck)*
- 8 - OTHER COMPARTMENT
- 9 - COMPARTMENT UNKNOWN

B. LONGITUDINAL LOCATION

	1. FORWARD SECTION		3. AFT SECTION
	2. CENTER SECTION		4. SECTION UNKNOWN

C. LATERAL LOCATION

	2. CENTER		3. RIGHT SIDE
	4. LEFT SIDE		9. UNKNOWN

D. DIRECTION FACING

	1. FORWARD		3. SIDEWARD
	2. AFT		9. UNKNOWN

E. USE OF SEAT

	0. NOT IN SEAT		2. BUNK/LITTER
	1. IN SEAT		9. UNKNOWN

2. METHOD OF ESCAPE *(More than one may apply)*

A. EJECTION

- 1-ACCOMPLISHED *(Free of aircraft)*
- 2-ATTEMPTED *(Did not clear aircraft)*
- 7-UNKNOWN IF ATTEMPT WAS MADE
- 8-UNKNOWN, SUSPECTED EJECTION
- 0-DEFINITELY NOT ATTEMPTED

B. BAILOUT

- 1-ACCOMPLISHED *(Free of aircraft)*
- 2-ATTEMPTED *(Did not clear aircraft)*
- 7-UNKNOWN IF ATTEMPT WAS MADE
- 8-UNKNOWN, SUSPECTED BAILOUT
- 0-DEFINITELY NOT ATTEMPTED

C. OTHER

- A-STANDARD EMERGENCY GROUND EGRESS
- 3-DID NOT ESCAPE
- 4-EXIT UNASSISTED *(Other than standard emergency ground egress)*
- 5-CARRIED/ASSISTED OUT
- 6-BLOWN/THROWN OUT
- 8-UNKNOWN IF ESCAPE ACCOMPLISHED
- 9-ESCAPE, METHOD UNKNOWN

3. INTENT FOR ESCAPE

	1-INTENT.		2-UNINTENT.		9-UNKNOWN

4. EXIT USED

- 1-NORMAL EXIT *(Ejection after blowing canopy)*
- 2-EMERGENCY EXIT
- 3-NORMAL EXIT *(Through canopy)*
- 8-OTHER
- 9-UNKNOWN

5. COCKPIT/CABIN CONDITION AFTER IMPACT

- 0-NO DAMAGE *(Other than canopy loss, etc.)*
- 1-MINOR DAMAGE *(Definitely habitable)*
- 2-REASONABLY INTACT *(Probably habitable)*
- 3-MAJOR DAMAGE *(Probably not habitable)*
- 4-DESTROYED *(Definitely not habitable)*
- 9-UNKNOWN

6. ORDER OF ESCAPE (1st, 2nd, etc.)

7. REASON(S) FOR ESCAPE *(More than one may apply)*

	A-FIRE/EXPLOSION		G-WATER IMPACT
	B-LOSS OF CONTROL		H-GROUND STRUC. IMPACT
	C-ENGINE FAILURE		J-LAUNCH FAILURE
	D-FUEL EXHAUSTION		K-ARRESTMENT FAILURE
	E-STRUCTURAL FAILURE		Y-OTHER
	F-MID-AIR COLLISION		Z-UNKNOWN

8. COMMUNICATIONS PRIOR TO ESCAPE

- 1-DISTRESS SIGNAL TRANSMITTED
- 2-POSITION FIX TRANSMITTED
- 3-EMERGENCY IFF *(Manual)*
- 4-EMERGENCY IFF *(Automatic)*
- 9-UNKNOWN
- 0-NONE

9. NUMBER OF PREVIOUS

EJECTIONS	EMERGENCY PARACHUTE JUMPS	OTHER PARACHUTE JUMPS

10. TERRAIN OF PARACHUTE LANDING/CRASH SITE *(More than one may apply)*

	A-OPEN SEA		M-DENSE WOODS
	B-LARGE LAKE		N-IN TREES
	C-RIVER		T-THROUGH TREES
	D-DEEP WATER, OTHER		P-RAVINE/STEEP SLOPE
	E-SHALLOW WATER		Q-ROCKS
	F-DEEP SNOW		R-IN/NEAR FIREBALL
	G-THICK ICE		S-DESERT
	H-MARSH/SWAMP/MUD		O-FLAT
	I-HARD GROUND		Z-UNKNOWN
	J-SOFT GROUND		Y-OTHER *(Describe)*
	K-BUILDING		U-MOUNTAINS
	L-RUNWAY/OVERRUN		

11. AIRCRAFT ATTITUDE AT TIME OF ESCAPE *(Either in flight or after crash, ditching, etc.)*

	1-NOSE UP		0-NOSE DOWN		DEGREES
	1-RIGHT BANK		0-LEFT BANK		DEGREES

- A-NOSE DOWN SPIN
- B-FLAT SPIN
- C-OSCILLATING SPIN
- D-ROLLING
- E-TUMBLING
- F-DISINTEGRATION
- G-INVERTED
- H-MUSHING
- I-STRAIGHT AND LEVEL
- Z-UNKNOWN
- Y-OTHER

12. EJECTION SEAT/PARACHUTE TRAINING *(Not required for passengers who had no opportunity to escape.)*

TYPE OF TRAINING		TOTAL HRS. IN TNG	DATE OF LAST TNG	ROLE[1]	(LEAVE BLANK)
LECTURES/ DEMONSTRATIONS					
UNARMED EJECTION SEAT					
ARMED SEAT ON TOWER					
TRAINING FILMS					
PARASAIL TRAINING	LAND				
	WATER				
JUMP SCHOOL					
OTHER *(Specify)*					

[1] *Use the following codes to show role training played in this mishap.*

- 0-NO IMPORTANCE
- 1-TRAINING DEFINITELY HELPED
- 2-TRAINING POSSIBLY HELPED
- 3-LACK OF TRAINING DEFINITELY A FACTOR
- 4-LACK OF TRAINING POSSIBLY A FACTOR
- 9-UNKNOWN

NAME OF INDIVIDUAL	SSAN

VII. EJECTION OR BAILOUT *(Complete for all inflight escapes and ejections)*

1. TIME FROM ONSET NTIL ESCAPE ATTEMPT WAS INITIATED

HOURS	MINUTES	SECONDS

2. DELAY IN INITIATING ESCAPE DUE TO

	1- ATTEMPTING TO OVERCOME PROBLEM		2- AVOIDING POPULATED AREA		3- AVOIDING UNSUITABLE TERRAIN
	4- GAINING ALTITUDE		5- LOSING ALTITUDE		6- LOSING AIRSPEED
	8- OTHER		9- UNKNOWN		

3. TERRAIN CLEARANCE AT TIME OF

ESCAPE *(Feet)*	PARACHUTE OPENING *(Feet)*	AIRSPEED AT TIME OF ESCAPE
		KIAS

4. PROTECTIVE HELMET / HELMET VISOR LOWERED

TIME	CHIN STRAP FASTENED 1-YES	0-NO	9-UNK	DUAL 1-YES	0-NO	9-UNK	SINGLE 1-YES	0-NO	9-UNK
BEFORE EMERG.									
DURING EGRESS									
DURING CHUTE LANDING									

CHIN STRAP FASTENED SNUGLY			NAPE STRAP FASTENED SNUGLY		
1-YES	0-NO	9-UNK	1-YES	0-NO	9-UNK

5. ZERO LANYARD

A. WHEN CONNECTED

	0-AVAILABLE/NOT CONNECTED		1-PRIOR TO EMERGENCY
	2-PRIOR TO ESCAPE DURING EMERGENCY		3-TIME UNKNOWN
	8-NA/NOT AVAILABLE		9-UNKNOWN

B. SURVIVAL FACTOR

	0-NOT A FACTOR IN SURVIVAL		1-FACTOR IN SURVIVAL
	2-NOT A FACTOR IN NONSURVIVAL		3-FACTOR IN NONSURVIVAL

6. AUTOMATIC LAP BELT RELEASE

	0-DID NOT OPEN OR RELEASE		1-RELEASED AUTO. AS DESIGNED		2-OPENED MANUALLY		
	3-OPENED INADVERTENTLY		7-NOT CONNECTED		8-UNK HOW RELEASED		9-UNKNOWN IF RELEASED

7. REMOVAL OF AIRCRAFT CANOPY

A. INTENT

	1-INTENT.		2-UNINTENT.		9-UNKNOWN

B. INITIATED BY

	1-THIS INDIVIDUAL		2-ANOTHER INDIVIDUAL		9-OTHER/UNKNOWN

C. REMOVAL

	0-DEF. NOT ATTEMPTED		1-ACCOMPLISHED
	2-ATTEMPTED *(Unsuccess.)*		3-UNK IF ATTEMPTED

D. METHOD OF INITIATING REMOVAL

	1-ARM REST/LEG BRACE		2-FACE CURTAIN
	3-D RING		4-MANUALLY UNLOCKED
	5-EXTERNAL FORCE		8-OTHER *(Describe)*
	9-UNKNOWN		

8. EJECTION

A. INTENT

	1-INTENTIONAL		2-UNINTENT.		9-UNKNOWN

B. INITIATED BY

	1-THIS INDIVIDUAL		2-ANOTHER INDIVIDUAL		9-OTHER UNKNOWN

C. METHOD

	1-ARM REST/LEG BRACE		2-FACE CURTAIN
	3-D RING		4-SEAT SEQUENCE
	5-IMPACT		6-FIRE
	7-MECHANICAL FAILURES		8-OTHER EXTERNAL FORCE
	9-UNKNOWN		

9. BODY POSITION AT EJECTION
(As compared to the optimal position)

	HEAD	HIPS	FEET	ELBOWS
1-OPTIMAL				
2-FORWARD				
3-UPWARD				
4-LATERAL				
9-UNKNOWN				

10. POSITION OF EJECTION SEAT AT TIME OF EJECTION

	1-FULL UP		2-FULL DOWN
	3-INTERMEDIATE POSITION		9-UNK/NOT APPLICABLE

11. METHOD OF SEPARATING MAN FROM SEAT

	0-DID NOT SEPARATE		1-SEAT SEPARATOR		2-SPONTANEOUS TUMBLING
	3-PUSHED SELF AWAY		4-PERSONNEL PARACHUTE		8-OTHER
	9-UNKNOWN				

12. TYPE OF SEAT SEPARATOR

	0-NONE		1-ROTARY		2-BLADDER
	3-PARACHUTE		4 SNUBBING		5-SEAT RETARD. CHUTE

13. METHODS OF DEPLOYING PARACHUTE

	0-NON DEPLOYED		1-AUTOMATIC TIMER
	2-ANEROID		3-BALLISTIC DEVICE
	4-ZERO LANYARD		5-STATIC LINE
	6-MANUALLY		8-OTHER
	9-UNKNOWN		

14. PARACHUTE OPENING SHOCK

	0-NEGLIGIBLE		1-MODERATE
	2-SEVERE		9-UNKNOWN

15. PARACHUTE OSCILLATIONS

	0-NEGLIGIBLE	1-MODERATE	2-SEVERE	9-UNK
A. DURING DESCENT				
B. DURING LANDING				

16. PARACHUTE DAMAGE *(Give number)*

SEVERED SHROUD LINES	TORN PANELS, MAJOR
MISSING PANELS	TORN PANELS, MINOR

17. CAUSE OF PARACHUTE DAMAGE

	1-OPENING SHOCK		2-EJECTION SEAT
	3-FOULED ON AIRCRAFT		4-FIRE
	8-OTHER *(Describe)*		9-UNKNOWN/NONE

18. FOUR LINE RELEASE

	1-YES	0-NO	8-PARTLY	9-UNK
ATTEMPTED				
SUCCEEDED				
STOPPED OSCILLATIONS				
SLOWED DESCENT				
PROVIDED STEERING				

19. DIRECTION OF DRIFT/OSCILLATION FACED AT CHUTE LANDING

	1-DIRECTLY FACING		2-FACING AWAY		3-QUARTERING FACING
	4-QUARTERING BACK		5-DIRECTLY SIDEWAYS		9-UNKNOWN

20. LANDING CONDITIONS

A. TOTAL WT UNDER PARACHUTE *(Lbs.)*	B. SURFACE WIND *(Knots)*
C. DRAGGED BY CHUTE: 1-YES / 0-NO	D. DISTANCE DRAGGED *(Yards)*

21. PARACHUTE LANDING POSITION TECHNIQUES

A		0-COULD NOT SEE		1-LOOKING AHEAD
		2-LOOKING DOWN		9-OTHER/UNKNOWN
B		1-FELL OBLIQUELY		2-FELL BACKWARD
		3-FELL FORWARD		9-OTHER/UNKNOWN
C		1-MUSCLES TENSED		2-MUSCLES TOO TENSE
		3-TOO RELAXED		9-OTHER/UNKNOWN
D		1-PROPER POSITION		2-KNEES LOCKED
		3-ARMS IN POOR POSIT.		9-OTHER/UNKNOWN

22. DEPLOYED BEFORE LANDING

	1-YES	0-NO	9-UNK
A. SURVIVAL KIT			
B. LIFE RAFT			
C. LIFE VEST			

23. [illegible]

	[illegible]
	[illegible]
	[illegible]
	[illegible]
	[illegible]

USAF MISHAP REPORT

(Fill in all spaces applicable. If additional space is needed, use additional sheet(s).)

1. DATE OF OCCURRENCE *(Day, Month and Year)*	2. VEHICLE(S) OR MATERIEL INVOLVED *(Model designation and serial no. if applicable)*	3. FOR GROUND ACCIDENTS ONLY *(Base Code and Report Serial No.)*

4. PLACE OF OCCURRENCE. STATE, COUNTY, DISTANCE AND DIRECTION FROM NEAREST TOWN. IF ON BASE, IDENTIFY. IF OFF BASE GIVE DISTANCE FROM NEAREST BASE.	5. HOUR AND TIME ZONE LOCAL	6. ☐ DAY ☐ NIGHT ☐ DAWN ☐ DUSK

7. ORGANIZATION POSSESSING OR OWNING VEHICLE OR MATERIEL AT TIME OF MISHAP

MAJOR COMMAND	SUBCOMD OR AF	AIR DIVISION	WING	GROUP	SQ OR UNIT	NAME & BASE CODE

8. *(List organizations of second vehicle, if they differ from item 7 above)*

9. ORGANIZATION AND BASE SUBMITTING REPORT *(Do not abbreviate)*

10. LIST OF PERSONNEL DIRECTLY INVOLVED

(See AFR 127-2 for specific instructions)

LAST NAME, FIRST NAME, MIDDLE INITIAL	GRADE	SSAN	ASSIGNED DUTY	AERO RATING	DEGREE INJURY [1] *(Use Abbr)*	DAYS LOST ON TT ONLY

[1] *(Enter applicable letter(s) in DEGREE INJURY column. None-N; Temporary Total-TT; Permanent Partial-PP; Permanent Total-PT; Fatal-F; Missing-M)*

11. FACTUAL SUMMARY OF CIRCUMSTANCES. GIVE A DETAILED HISTORY OF FLIGHT OR CHRONOLOGICAL ORDER OF FACTS AND CIRCUMSTANCES LEADING TO THE MISHAP. THE RESULTS OF INVESTIGATION WILL BE CONTAINED IN THE "ANALYSIS PART" OF THE REPORT. ANALYSIS OF AND CONCLUSIONS DRAWN FROM ORAL OR WRITTEN STATEMENTS OBTAINED ONLY IN THE INTEREST OF MISHAP PREVENTION WILL NOT BE INCLUDED IN THIS SUMMARY.

12. AUTHENTICATION

CERTIFICATION BY *(Title)*	TYPED NAME AND GRADE	SIGNATURE	DATE

APPENDIX D

SAMPLE FORMAT OF SYSTEM SAFETY HAZARD ANALYSIS

SYSTEM ______________

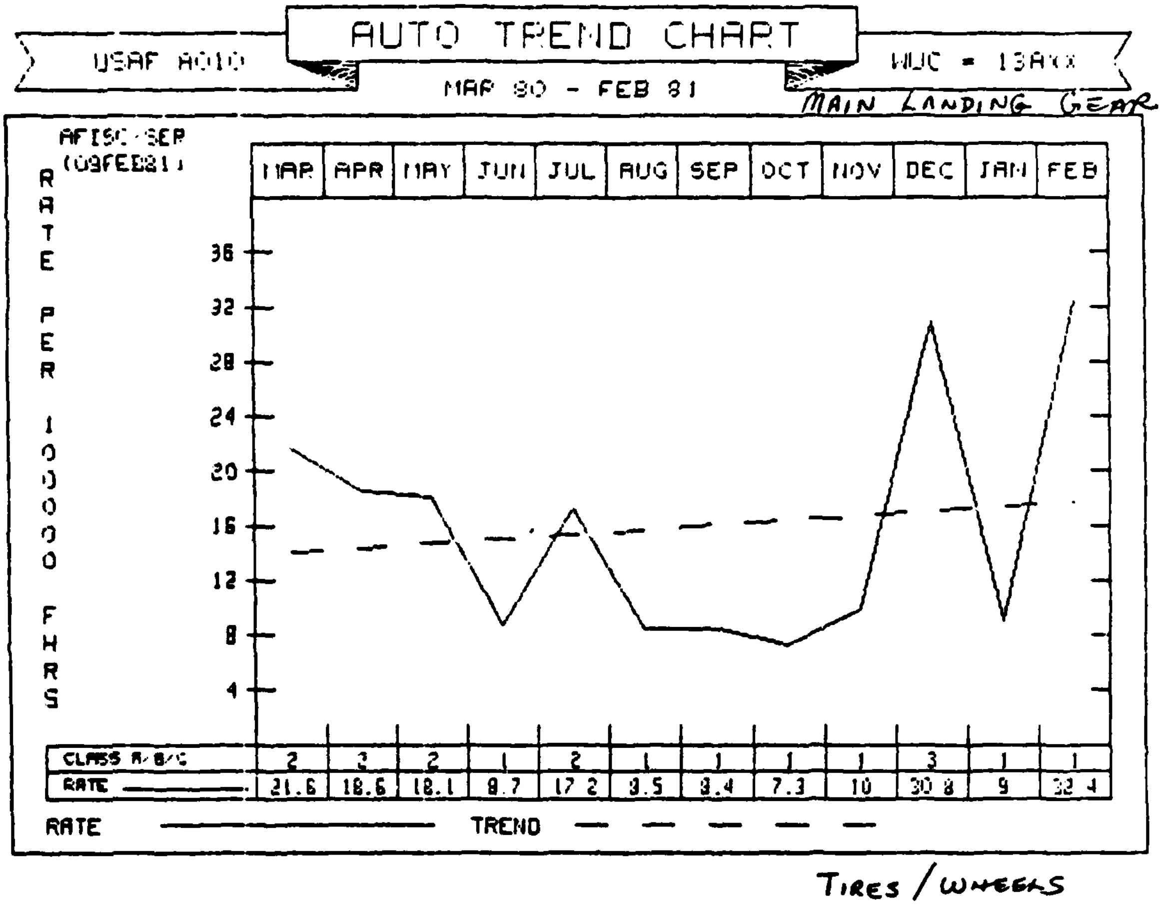
SUBSYSTEM ___________

COMPONENT ___________

HAZARD/ UNDESIRED EVENT	PHASE	CAUSE	EFFECT	CLASSI-FICATION	CORRECTIVE ACTION/MINI-MIZING PRO-VISIONS
Descriptive short title	Program phase in which the hazard may occur, e.g. ground operation, take off, climb, in flight, return to base, landing	Events which create hazard	Description of the effects of the hazard on both personnel and equipment	Hazard which depends on the effect. First col. is classification of hazard without any corrective action or minimizing provisions. The second col. is the classification after corrective action has been taken.	Description of action taken to eliminate or minimize and control the hazard. All safety design requirements, safety procedures, probabilities of occurrence, safety devices used, and any other significant action taken to minimize and control the hazards should be included in this column.

APPENDIX E

SAMPLE TREND CHART



FLYING HOURS FOR THIS OUTPUT

9259	10759	11036	11533
11607	11754	11090	13665
10023	9725	11137.7	3088.57

SLOPE = .342048443357 INTERCEPT = 13.66263757

CORRELATION COEFFICIENT = .139394294025

90 % CONFIDENCE INT FOR SLOPE =-1.36992466635 TO 2.05402155306

BIBLIOGRAPHY

Adelfio, S.A., and Nolan, C.F., Principles and Applications of Boolean Algebra, Hayden Book Company, Inc., 1964.

Ayoub, M.A., "The Problem of Occupational Safety," Industrial Engineering, V. 7, No. 4, p. 20, April, 1975.

Barlow, R.E., Fussell, J.B., and Singpur Walla, N.D., Reliability and Fault Tree Analysis, Theoretical and Applied Aspects of System Reliability and Safety Assessment, Society for Industrial and Applied Mathematics, 1975.

Barlow, R.E., and Lambert, H.E., "Introduction to Fault Tree Analysis," Reliability and Fault Tree Analysis, Society for Industrial and Applied Mathematics, Pp. 7-35, 1975.

Barlow, R.E., and Proschan, F., Statistical Theory of Reliability and Life Testing Probability Models, Holt, Rinehart and Winston, Inc., 1975.

Barnhart, W., Billings, C., Cooper, G., Gilstrap, R., Lauber, J., Orlady, H., Puskas, B., Stephens, W., "A Method for the Study of Human Factors in Aircarft Operations," NASA Technical Memorandum, Report No. A-6237, September, 1975.

Brown, D.B., Systems Analysis and Design for Safety, Prentice Hall, 1976.

Chapanis, A., Research Techniques in Human Engineering, Johns Hopkins, 1959.

DeGreene, K.B., "Systems Analysis Techniques" in Systems Psychology by K.B. DeGreene, Pp. 81-85, McGraw-Hill, 1970.

Duncan, A.J., Quality Control and Industrial Statistics, R.D. Irwin, Inc., 1976.

Flanagan, J.C., "The Critical Incident Technique," Psychological Bulletin, V. 51, No. 4, Pp. 327-358, July, 1954.

Gilmore, C., Accident Prevention and Loss Control, American Management Association, Inc., 1970.

Hammer, W., Handbook of System and Product Safety, Prentice Hall, Inc., 1972.

Heschel, M.S., "Hazards Reduction Improves Safety," Industrial Engineering, V. 6, No. 3, Pp. 8-10, March, 1974.

Johnston, W.L., and Rogers, T.R., "Measuring Safety Performance," Industrial Engineering, V. 7, No. 12, Pp. 19-21, December, 1975.

Kogler, K.J., Identification of Critical Failures and Cost Effective Reliability Improvement Approaches, U.S. Army Aviation System Command, June, 1976.

Lambert, H.E., "Measures of Importance of Events and Cut Sets in Fault Trees," Reliability and Fault Tree Analysis, Pp. 77-100, Society for Industrial and Applied Mathematics, 1975.

Lindsey, G.D., and Brown, W.R., Analysis of FY 78 Army Aircraft Accidents, U.S. Army Safety Center, May, 1979.

Lowrance, W.W., Of Acceptable Risk, William Kaufman, Inc., 1976.

Miller, C.O., "The Design-Induced Part of the Human Error Problem in Aviation," Journal of Air Law and Commerce, V. 42, Pp. 119-131, Winter, 1976.

Peterson, D., Techniques of Safety Management, McGraw-Hill, 1971.

Ricketson, D.S., Kennamore, J.R., and Callen, J.R., Pilot-Error Accidents Aren't All Pilot, U.S. Army Agency for Aviation Safety, May, 1975.

Rogers, W.P., Introduction to System Safety Engineering, John Wiley and Sons, Inc., 1971.

Roland, H.E., Safety--An Investment Alternative, The Safety Center, University of Southern California, 1975.

Simonds, R.H., and Grimaldi, J.V., Safety Management, R.D. Irwin, Inc., 1963.

U.S. Air Force, "The U.S. Air Force Mishap Prevention Program," A.F. Regulation 127-2.

U.S. Naval Safety Center, Handbook for Aircraft Accident Investigation, 1973.

U.S. Navy, "The Naval Aviation Safety Program," OPNAV Instruction 3750.6, October, 1980.

Warwick, W.B., Rear Adm., "Human Factors in Navy Safety," Invited Presentation: 24th Annual Meeting of the Human Factors Society, 1980.

Worick, W.W., Safety Education, Prentice Hall, 1975.

Zeller, A.F., "Accidents and Safety" in Systems Psychology by K.B. DeGreene, PP. 131-150, McGraw-Hill, 1970.

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